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USER MANUAL FOR THE BASE OF Aircraft DATA (BADA) REVISION 3.7

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Abstract :

The Base of Aircraft Data (BADA) provides a set of ASCII files containing performance and operating procedure coefficients for 294 different aircraft types. The coefficients include those used to calculate thrust, drag and fuel flow and those used to specify nominal cruise, climb and descent speeds. User Manual for Revision 3.7 of BADA provides definitions of each of the coefficients and then explains the file formats. Instructions for remotely accessing the files via Internet are also given.

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SUMMARY

The Base of Aircraft Data (BADA) provides a set of ASCII files containing performance and operating procedure coefficients for 294 different aircraft types. The coefficients include those used to calculate thrust, drag and fuel flow and those used to specify nominal cruise, climb and descent speeds. The User Manual for Revision 3.7 of BADA provides definitions of each of the coefficients and then explains the file formats. Instructions for remotely accessing the files via Internet are also given.

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USER MANUAL MODIFICATION HISTORY

Issue Number	Release Date	Comments
Revision 2.1 Issue 1.0	31.05.94	First release of document
Revision 2.2 Issue 1.0	25.01.95	Released with BADA Revision 2.2 - 8 new aircraft models - 2 modified aircraft models - 2 modified equivalences - 6 removed equivalences - 14 new equivalences - modified file formats - additional Synonym File - corrections to formulas in previous version of document - additional description of total-energy and standard atmosphere equations
Revision 2.3 Issue 1.0	08.06.95	Released with BADA Revision 2.3 - document format modified to be consistent with EEC Technical Note standards - new A/C models for B73V and D328 - MD11 changed from equivalence to direct support - generic military fighter model, FGTR, replaces specific fighter models - maximum payload parameter added to all OPF files - Performance Tables Files (*.PTF) introduced - ISA equations used for TAS/CAS conversions instead of approximations (Section 3.2) - use only one formula for correction of speeds at mass values different from reference mass (Section 3.3) - add specification of minimum speed as function of stall speed (Section 3.4) - specification of transition altitude calculated added (Section 4.1) - speed schedules modified for climb (Section 4.1) and descent (Section 4.3) - modify Internet address for remote access and EUROCONTROL contact person (Section 6) - removed Section 7 (General Comments)

Issue Number	Release Date	Comments
Revision 2.4 Issue 1.0	04.01.96	Released with BADA Revision 2.4 - new A/C model for FK70 - C421 changed from equivalence to directly supported - 10 new equivalences - 1 modified equivalence - 3 re-developed models - introduction of dynamic maximum altitude - new temperature correction on thrust - modified max.alt for 4 models - modified minimum weight for 2 models - modified temperature coefficients for 12 models - esf calculation for constant CAS below tropopause changed from binomial approximation to exact formula - cruise Mach numbers changed for 4 models - change in altitude limit for descent speed
Revision 2.5 Issue 1.0	20.01.97	- re-developed models: EA32, B737, B73S, AT42, B767, DC9, BA46, FK10, MD80. - new model: CL65, DH83 - change of minimum speeds - change of climb/descent speed schedules - cruise fuel flow correction - buffeting speed for jet a/c - addition of BADA.GPF file - definition of acceleration limits, bank angles and holding speeds - 38 new equivalences added (SA4, SA5, SweDen 96) - 1 modified equivalence (B74S) - modified climb/cruise speeds (BE90, BE99, E120, PA42, FK50, B73F, B767,B747, B727, DA20) - Format changes in OPF file - Header changes in PTF file - Temperature influence on thrust limitation changed - Unit of Vstall in OPF file changed to KCAS - Correction of typing errors - Correction of APF file format explanation
Revision 2.6 Issue 1.0	01.09.97	- Added non-clean drag and thrust data for: EA32, B73S, MD80, B737, B747, FK10, AT42, B767 and CL65 models - All models mentioned above were re-developed using new clean drag data. - ND16, E120 and FK50 were re-modelled to correct the cruise speed capability.

Issue Number	Release Date	Comments
		- Change of speed schedule in the take-off / initial climb phase and approach / landing phase - Change in descent thrust algorithm - Use of exact formula for density below tropopause instead of approximation. - Addition of formula for pressure above tropopause - Change of buffeting limit to 1.2g (was 1.3g) - Change of OPF file format - Buffeting coefficients for B757 and MD80 were corrected. - Hmo for B747 model was corrected to 45,000 ft - Low altitude descent behaviour corrected for: SW3, PAYE, DA50, DA10, D328, C421, BE99, BE20 and BE90 models - Correction of some minor typing errors - dynamic maximum altitude coefficients changed for B747, B74F, C130 and EA30 - Saab 2000 (SB20) added as equivalent of D328 - Modified algorithm for lift coefficient
Revision 3.0 Issue 1.0	01.03.98	- Climb speed law changed for jet aircraft - Descent speed law changed for jet, turbo and piston - Reduced power climbs - B777, SB20 and B73X models were added - DA01 model was removed - Use of ICAO doc. 8643/25 standard, which resulted in the removal of 4 additional models - B73F and B757 remodelled - MD90 added as equivalence model - Cruise and descent speeds for several turboprops changed - Climb thrust for several a/c changed - Removal of C_{m16} from drag expression
Revision 3.1 Issue 1.0	01.10.98	- Released with BADA Revision 3.1 - Descent & cruise speeds for several jet aircraft changed: DC9, BA46, CL60 - Descent, cruise & climb speeds for several turboprops changed: D228, SH36 - Maximum Operating speed for several a/c changed: PA42 - Stalling speed for several a/c changed : DC8, T154 - Removed formula for air density calculation above tropopause - Addition of Appendix D : Solutions for buffeting limit algorithm

Issue Number	Release Date	Comments
		- Removed Section 3.7.2 : Maximum Take-Off Thrust - Description for Cred parameter added - Correction of some minor typing errors - Modified PTF File format (Flight Level): Section 6.6 - Cruise CAS schedule for jet & turbo aircraft (Section 4.2)
Revision 3.3 Issue 1.0		Released with BADA Revision 3.3 - Standard atmosphere explanation added - Correction of some typing errors, minor changes in the layout and equations presentation. - Several aircraft types have changed ICAO's designator according to the ICAO doc.8643/27. Aircraft types affected by the RD3 are as follows: A300, ATR, B707, B727, B73A, B73B, B73C, B74A, B74B, B757, B767, B777, CARJ, DC8, DHC8, JSTA, JSTB, P31T, PA28, PA42. That resulted in: modification of the name of the OPF and APF files, addition of new models as synonyms, modification of Synonym.NEW and Synonym.LST files. - B73A, B757, MD80, B73B, F100, B727, CARJ, FA20, FA50, D228, T154 aircraft models have been re-modelled - A319, A321, A306, AT72 models have been added - Climb, cruise and descent speeds changed for several models.
Revision 3.3 Issue 1.0		- Ground TOL for B73C has been modified. - MD80: Cd0 and Cd2 for IC and TO added, maximum altitude at MTOW, ISA weight gradient on maximum altitude Gw and temperature gradient Gt on maximum altitude have been changed - BA46 maximum altitude at MTOW, ISA weight gradient on maximum altitude Gw have been changed - E145 was added as equivalent of CRJ1 - A478 was added as equivalent of AT72
Revision 3.4 Issue 1.0	June 2002	Released with BADA Revision 3.4 - correction of some typing errors - in chapter 3.5 configuration threshold altitude values replaced with Hmax,i ,while the corresponding numbers are listed in chapter 5.6 - Appendix B: a new column is added to the table; providing the information on maximum altitude that an aircraft can reach at MTOW (h_{max}) - FGTN aircraft model added - FGTH aircraft model added - FGTL aircraft model added

Issue Number	Release Date	Comments
		- FGTR aircraft model removed - DC-9 aircraft model re-modelled - D228 cruise and descent speed modified - SH36 cruise and descent speed modified - B738 maximum operational altitude modified - AT72 cruise speed corrected - PA34 minimum mass modified - B734 aircraft model added - B735 aircraft model added - E145 aircraft model added - B737 aircraft model added - AT45 aircraft model added - B762 aircraft model added - B743 aircraft model added - Removal of several existing OPF and APF files due to the change of ICAO aircraft designators according to RD3: A330, A340, BA46, DC9, MD80 - Addition of several new OPF and APF files due to the change of ICAO aircraft designators according to RD3: A333, A343, B461, DC94, MD83 - Addition of new equivalence aircraft types: A332, A342, A345, A346, B461, B462, B463, DC91, DC92, DC93, DC95, MD81, MD82, MD87, MD88, A124, AC80, AC90, AC95, AJET, AMX, AN72, ATLA, B1, B350, B739, B74D, BDOG, BE10, BE40, BE76, BER4, C17, C72R, C77R, C82R, C210, C212, C337, C526, C56X, CRJ7, E135, EUFI, F1, FT2H, F104, G222, GLF5, HAWK, H25A, H25C, IL96, JS1, JS3, JS20, LJ24, M20T, M20P, K35R, N262, P28T, P28B, PA32, PAY4, P68, PA44, SB05, T204, TBM7 - Modification of the value for Maximum bank angles for civil flight during HOLD in BADA.GPF file - Configuration Management of BADA files have been changed; files have been migrated from RCS to Continuus Configuration Management System. That resulted in the modification of the “identification” part of all BADA files given in the header.
Revision 3.5 Issue 1.0	July 2003	Released with BADA Revision 3.5 - correction of some typing errors - B712 aircraft model added - LJ45 aircraft model added - C750 aircraft model added

Issue Number	Release Date	Comments
		- RJ85 aircraft model added - B736 aircraft model added - B753 aircraft model added - A332 aircraft model added - B772 re-modelled - B738 re-modelled - B763 re-modelled - B703 WTC modified - JS41 WTC modified - Addition of new syn. aircraft types: P180, GLEX, C30J, J328, A7, B52, ETAR, F117, L159 - Modification of BADA models for existing synonym aircraft types: C17, GLF3, GLF3, GLF4, GLF5 - SYNONYM_ALL.LST file added.
Revision 3.6 Issue 1.0	July 2004	Released with BADA Revision 3.6 The following models of aircraft added in BADA 3.6: - Dash 8-100: **DH8A** - Boeing MD82: **MD82** - Boeing B767-400: **B764** - Boeing B777-300: **B773** - BAE 146-200: **B462** The following models of aircraft have been re-modelled in BADA 3.6: - Airbus A300B4-203: **A30B** - Airbus A310: **A310** - Airbus A319: **A319** - Airbus A320: **A320** - Airbus A321: **A321** - Airbus A330-301: **A333** - Airbus A340-313: **A343** - Boeing B737-200: **B732** - Boeing B737-300: **B733** - Boeing B747-200: **B742** - Boeing B747-400: **B744** - Boeing B757-200: **B752** Addition of new synonym aircraft types: A3ST, ASTR, B701, C441, GALX, J728, K35A, K35E, L29B, LJ25, LJ60, NIM, PC12, R135, RJ1H, RJ70, P32R, C208, AA5, S76, DC3, BLAS, AEST, EC35, PAY1, PA18, BE55, C170, B461.

Issue Number	Release Date	Comments
		Correction of syntax errors in BADA files: - Boeing B777-200: **B772** - ATR42-500: **AT45**
Revision 3.7 Issue 1.0	March 2009	Released with BADA Revision 3.7 - Modification of the values for constants g and R in Section 3. - New description of formula 3.1-8 to match its actual use in some models. - Coefficient CVmin, TO is no longer used in climb speed schedule, only in flight envelope determination. - Numbering of several equations changed due to reorganisation of related sections. - Change of descent thrust computation when CTdes,app and CTdes, ld are null in Section 3.7.3. - Clarification of descent fuel flow computation in Section 3.9. - Additional information on climb and descent speed schedules in Section 4. - Update of some Fortran format descriptions in Section 6. - Additional reasons for ROCD discontinuities added in Section 6.6. - Introduction of new PTD file format. - Update of Section 7 to describe the new means of access to the BADA files. - Remodelling of 71 a/c types from BADA 3.6 - more details in [RD8]. - Addition of 12 new a/c models for following a/c types: A346, A388, BE58, C510, CRJ2, CRJ9, DA42, DH8D, E135, E170, E190, EA50. - All synonym aircraft have been re-evaluated and some reassigned – more details in [RD12] reassigned.

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1. INTRODUCTION

1.1. IDENTIFICATION

This document is the User Manual for the Base of Aircraft Data (BADA) Revision 3.7. This manual replaces the previous User Manual for BADA Revision 3.6 [RD1].

1.2. PURPOSE

BADA is a collection of ASCII files which specifies operation performance parameters, airline procedure parameters and performance summary tables for 294 aircraft types. This information is designed for use in trajectory simulation and prediction algorithms within the domain of Air Traffic Management (ATM). All files are maintained within a configuration management system at the EUROCONTROL Validation Infrastructure Centre of Expertise located at the EUROCONTROL Experimental Centre (EEC) in Brétigny-sur-Orge, France.

This document describes the mathematical models on which the data is based and specifies the format of the files which contain the data. In addition, this document describes how the files can be remotely accessed.

1.3. DOCUMENT ORGANISATION

This document consists of seven sections including Section 1, the Introduction. A list of referenced documents along with a glossary of acronyms and symbols are included in this section.

Section 2: Revision Summary, summarises the differences between BADA 3.7 and the previous revision BADA 3.6.

Section 3: Operation Performance Models, defines the set of equations, which are used to parameterise aircraft performance. This includes models of aerodynamic drag, engine thrust, and fuel consumption.

Section 4: Airline Procedure Models, defines the set of parameters which is used to characterise standard airline speed procedures for climb, cruise, and descent.

Section 5: Global Aircraft Parameters, defines the set of global aircraft parameters that are valid for all, or a group of, aircraft.

Section 6: File Structure, describes the files in which the BADA aircraft parameters are maintained. Six types of files are identified:

- Synonym Files listing the supported aircraft types;
- Operations Performance Files (OPF) containing the performance parameters for a specific aircraft type;
- Airline Procedures Files (APF) containing speed procedure parameters for a specific aircraft type;
- Performance Table Files (PTF) containing summary performance tables of true air speed, climb/descent rates and fuel consumption at various flight levels for a specific aircraft type;
- Performance Table Data (PTD) containing detailed performance data at various flight levels for a specific aircraft type;

- Global Parameters File (GPF) containing parameters that are valid for all aircraft or a group of aircraft, for instance all turboprops or all military aircraft.

Section 7: Remote File Access to BADA, provides instructions on how to remotely access BADA files from the EUROCONTROL computing facilities over the Internet.

Two appendices are also provided with this document. **Appendix A** provides a list of the aircraft types supported by BADA 3.7 and **Appendix B** gives solutions for a buffeting limit algorithm.

1.4. REFERENCED DOCUMENTS

RD1 User Manual for the Base of Aircraft Data (BADA) Revision 3.6; EEC Note No. 10/04, September 2004.

RD2 Aircraft Type Designators, ICAO Document 8643/36, November 2008.

RD3 Aircraft Modelling Standards for Future ATC Systems; EUROCONTROL Division E1 Document No. 872003, July 1987.

RD4 Manual of the ICAO Standard Atmosphere; ICAO Document No. 7488, 2nd Edition, 1964.

RD5 BADA Product Management Document; EEC Technical Report No. 2009-008, April 2009.

RD6 Base of Aircraft Data (BADA) Aircraft Performance Modelling Manual: EEC Technical Report No. 2009-009, April 2009.

RD7 Memo on the Calculation of Energy Share Factor; EEC/FAS/BYR/95/50; 22 November 1995.

RD8 Revision Summary Document for the Base of Aircraft Data (BADA) Revision 3.7; EEC Technical Note 2009/004; April 2009.

RD9 Aircraft Performance Summary Tables for the Base of Aircraft Data (BADA) Revision 3.7; EEC Technical Note 2009/005; April 2009.

RD10 Aircraft Type Designators, ICAO Document 8643, Version 24-36.

RD11 BADA User Support Tool – User Guide, April 2009.

RD12 Synonym Aircraft Report for the Base of Aircraft Data (BADA) - Revision 3.7: EEC Technical Report No. 2009-007, April 2009.

RD13 Model Accuracy Summary Report for the Base of Aircraft Data (BADA) - Revision 3.7: EEC Technical Report No. 2009-006, April 2009.

1.5. GLOSSARY OF ACRONYMS

AGL	**A**bove **G**round **L**evel
APF	**A**irlines **P**rocedures **F**ile
ASCII	**A**merican **S**tandard **C**ode for the **I**nterchange of **I**nformation
ATM	**A**ir **T**raffic **M**anagement
BADA	**B**ase of **A**ircraft **Da**ta
CAS	**C**alibrated **A**ir**s**peed
EEC	**E**UROCONTROL **E**xperimental **C**entre
ESF	**E**nergy **S**hare **F**actor
ICAO	**I**nternational **C**ivil **A**viation **O**rganisation
ISA	**I**nternational **S**tandard **A**tmosphere
MASS	**M**ulti-**A**ircraft **S**implified **S**imulator
MLW	**M**aximum **L**anding **W**eight
MTOW	**M**aximum **T**ake-**o**ff **W**eight
OPF	**O**perations **P**erformance **F**ile
PTD	**P**erformance **T**able **D**ata
PTF	**P**erformance **T**able **F**ile
RCS	**R**evision **C**ontrol **S**ystem
ROCD	**R**ate of **C**limb or **D**escent
TAS	**T**rue **A**irspeed
TEM	**T**otal-**E**nergy **M**odel

1.6. GLOSSARY OF SYMBOLS

A list of the symbols used in equations throughout this document is given below along with a description. Where appropriate, the engineering units typically associated with the symbol are also given.

a	speed of sound	[m/s]
d	distance	[nautical miles]
f	fuel flow	[kg/min]
g	gravitational acceleration	[m/s^2]
$\frac{dh}{dt}$	rate of climb or descent	[m/s] or [ft/min]
h	altitude above sea level	[metres] or [ft]
C	general coefficient	
D	drag force	[Newtons]
m	aircraft mass	[tonnes] or [kg]
M	Mach number	
P	Actual pressure	[Pa]
P_0	Pressure at Sea level	[Pa]
R	real gas constant for air	[m^2/Ks^2]
S	reference wing surface area	[m^2]
T	thrust temperature	[N] [Kelvin]
V	speed	[m/s] or [knots]
ΔT	temperature difference	[Kelvin]
W	weight	[N]
η	thrust specific fuel flow	[kg/(min*kN)]
ρ	air density	[kg/m^3]

2. REVISION SUMMARY

This section summarises the aircraft types that are supported in BADA Revision 3.7 along with the updates that have been made from the previous release, BADA Revision 3.6.

2.1. SUPPORTED AIRCRAFT

BADA 3.7 provides operations and procedures data for a total of 294 aircraft types. For 103 of these aircraft types, data is provided directly in files. These aircraft types are referred to as being directly supported and referred to as aircraft original models. The way they have been identified is described in [RD6]. For the other 191 aircraft types, the data is specified to be the same as one of the directly supported 103 aircraft types. These aircraft types have been identified as being 'equivalent' to original aircraft models. They are referred to as synonym aircraft. More details on the way they have been identified is given in [RD12].

With three exceptions, each supported aircraft type is identified by a 4-character designation code assigned by the International Civil Aviation Organisation (ICAO) [RD2]. The exceptions are the models representing generic military fighters, which use the designators: FGTH, FGTL, FGTN.

The list of aircraft types supported by BADA 3.7 is given in Appendix A. In this Appendix the supported aircraft types are listed alphabetically by their designation code. For each aircraft type the aircraft name and type of BADA support (either original or synonym) is specified. Also, for each synonym aircraft, which is supported through equivalence, the corresponding equivalent aircraft type is specified.

2.2. UPDATES FOR BADA REVISION 3.7

Updates made to BADA Revision 3.7 from the previous revision 3.6 are listed below:

(a) Development of new documents.

(b) Editing changes in existing documentation.

(c) Re-modelling of 71 aircraft models.

(d) Addition of 12 new aircraft models.

(e) Re-evaluation of all synonym aircraft.

(f) Correction of syntax error in some BADA files.

(g) Implementation of new ICAO aircraft designators according to the ICAO doc. 8643/36.

(h) Deployment of BADA Support Application.

A more complete overview of all changes can be found in [RD8].

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3. OPERATIONS PERFORMANCE MODEL

This section defines the various equations and coefficients used by the BADA operations performance model.

The first two subsections describe the Total-Energy Model (TEM) equations and standard atmosphere equations respectively.

The remaining eight subsections define the aircraft model in terms of the eight categories listed below.

- aircraft type,
- mass,
- flight envelope,
- aerodynamics,
- engine thrust,
- reduced power,
- fuel consumption and
- ground movement

3.1. TOTAL-ENERGY MODEL

The Total-Energy Model equates the rate of work done by forces acting on the aircraft to the rate of increase in potential and kinetic energy, that is:

$$(T - D)\,V_{TAS} = mg\frac{dh}{dt} + mV_{TAS}\frac{dV_{TAS}}{dt} \qquad (3.1\text{-}1)$$

The symbols are defined below with metric units specified:

T	-	thrust acting parallel to the aircraft velocity vector	[Newtons]
D	-	aerodynamic drag	[Newtons]
m	-	aircraft mass	[kilograms]
h	-	altitude	[m]
g	-	gravitational acceleration	[9.80665 m/s^2]
V_{TAS}	-	true airspeed	[m/s]
$\frac{d}{dt}$	-	time derivative	[s^{-1}]

Note that true airspeed is often calculated in knots and altitude calculated in feet thus requiring the appropriate conversion factors.

Without considering the use of devices such as spoilers, leading-edge slats or trailing-edge flaps, there are two independent control inputs available for affecting the aircraft trajectory in the vertical plane. These are the throttle and the elevator.

These inputs allow any two of the three variables of thrust, speed, or ROCD to be controlled. The other variable is then determined by equation 3.1-1. The three resulting control possibilities are elaborated on below.

(a) Speed and Throttle Controlled - Calculation of Rate of Climb or Descent

Assuming that velocity and thrust are independently controlled, then equation 3.1-1 is used to calculate the resulting rate of climb or descent (ROCD). This is a fairly common case for climbs and descents in which the throttle is set to some fixed position (maximum climb thrust or idle for descent) and the speed is maintained at some constant value of calibrated airspeed (CAS) or Mach number.

(b) ROCD and Throttle Controlled - Calculation of Speed

Assuming that the ROCD and thrust are independently controlled, then equation 3.1-1 is used to calculate the resulting speed.

(c) Speed and ROCD Controlled - Calculation of Thrust

Assuming that both ROCD and speed are controlled, then equation 3.1-1 can be used to calculate the necessary thrust. This thrust must be within the available limits for the desired ROCD and speed to be maintained.

Case (a), above, is the most common such that equation 3.1-1 is most often used to calculate the rate of climb or descent. To facilitate this calculation, equation 3.1-1 can be rearranged as follows:

$$(T - D) \times V_{TAS} = mg\frac{dh}{dt} + m\,V_{TAS}\left(\frac{dV_{TAS}}{dh}\right)\left(\frac{dh}{dt}\right) \qquad (3.1\text{-}2)$$

Isolating the rate of climb or descent on the left hand side gives:

$$\frac{dh}{dt} = \frac{(T-D)V_{TAS}}{mg}\left[1+\left(\frac{V_{TAS}}{g}\right)\left(\frac{dV_{TAS}}{dh}\right)\right]^{-1} \qquad (3.1\text{-}3)$$

It has been shown by Renteux [RD3] that the last term can be replaced by an energy share factor as a function of Mach number, f {M}.

$$f\{M\} = \left[1+\left(\frac{V_{TAS}}{g}\right)\cdot\left(\frac{dV_{TAS}}{dh}\right)\right]^{-1}$$

This leads to:

$$\frac{dh}{dt} = \left[\frac{(T-D)V_{TAS}}{mg}\right] f\{M\} \qquad (3.1\text{-}4)$$

This energy share factor f {M} specifies how much of the available power is allocated to climb as opposed to acceleration while following a selected speed profile during climb.

For several common flight conditions equation 3.1-4 can be rewritten as is done below. A more comprehensive description of this process can be found in RD7:

(a) Constant Mach number in stratosphere (i.e. above tropopause)

$$\boxed{f\{M\} = 1.0} \tag{3.1-5}$$

Note that above the tropopause (approximately 11000 metres under ISA conditions) the air temperature and the speed of sound are constant. Maintaining a constant Mach number therefore requires no acceleration and all available power can be allocated to a change in altitude.

(b) Constant Mach number below tropopause:

$$\boxed{f\{M\} = \left[1 + \frac{\gamma R k_T}{2g} M^2\right]^{-1}} \tag{3.1-6}$$

where,

R	is the real gas constant for air, R = 287.05287 m^2/Ks^2
g	is the gravitational acceleration, g = 9.80665 m/s^2
k_T	is the ISA temperature gradient with altitude below the tropopause, k_T = -0.0065 °K/m
M	is the Mach number
γ	is the isentropic expansion coefficient for air, $\gamma = 1.4$

In this case, for a typical Mach number of 0.8 the energy share factor allocated to climb is 1.09.

This number is greater than 1 because below the tropopause, the temperature and thus, speed of sound decreases with altitude. Maintaining a constant Mach number during climb thus means that the true air speed decreases with altitude. Consequently, the rate of climb benefits from not only all the available power but also a transfer of kinetic energy to potential energy.

(c) Constant Calibrated Airspeed (CAS) below tropopause

$$\boxed{f\{M\} = \left\{1 + \frac{\gamma R k_T}{2g} M^2 + \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{-1}{\gamma-1}} \left\{\left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} - 1\right\}\right\}^{-1}} \tag{3.1-7}$$

In this case the energy share factor is less than one. A Mach number of 0.6 for example yields an energy share factor of 0.85.

This number is less than 1 because as density decreases with altitude, maintaining a constant CAS during climb requires maintaining a continual increase in true air speed. Thus, some of the available power needs to be allocated to acceleration leaving the remainder for climb.

(d) Constant Calibrated Airspeed (CAS) above tropopause.

$$f\{M\} = \left\{1 + \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{-1}{\gamma - 1}} \left[\left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}} - 1\right]\right\}^{-1} \qquad (3.1\text{-}8)$$

This formula is similar to (3.1-7), except that k_T is null since we are above the tropopause.

The energy share factors given above apply equally well to descent as to climb. The difference being that the available power is negative for descent.

In cases where neither constant Mach number nor constant CAS is maintained, the following energy share factors are used.

acceleration in climb	f{M} = 0.3
deceleration in descent	f{M} = 0.3
deceleration in climb	f{M} = 1.7
acceleration in descent	f{M} = 1.7

Note, for the cases of acceleration in climb or deceleration in descent, the majority of the available power is devoted to a change in speed.

For the cases of deceleration in climb or acceleration in descent, the energy share factor is greater than 1 since the change of altitude benefits from a transfer of kinetic energy.

3.2. STANDARD ATMOSPHERE

Calculations for lift, drag, and conversions from CAS to TAS and Mach number require the determination of several atmospheric properties as a function of altitude.

The equations used by BADA for the standard atmosphere and CAS/TAS conversion are summarised below. These equations are based on the International Standard Atmosphere (ISA) [RD4].

(a) Determination of the Tropopause

$$\boxed{h_{trop} = 11000 + 1000\ \Delta T_{ISA} / 6.5} \qquad (3.2\text{-}1)$$

Here the tropopause altitude, h_{trop}, is specified in metres.

ΔT_{ISA} is the temperature difference from the International Standard Atmosphere (ISA). That is, the temperature at sea level, T_0 , would be:

$$T_0 = (T_0)_{ISA} + \Delta T_{ISA} \qquad (3.2\text{-}2)$$

with

$$(T_0)_{ISA} = 288.15\ \text{K} \qquad (3.2\text{-}3)$$

For standard atmosphere conditions, ($\Delta T_{ISA} = 0$) the tropopause is at 11000 metres altitude.

(b) Determination of Temperature

Above the tropopause, the temperature is a constant, that is,

$$\boxed{T_{trop} = 216.65\ K} \qquad (3.2\text{-}4)$$

Below the tropopause, the temperature is calculated as a function of altitude as follows:

$$T = T_0 - 6.5 * h/1000 \qquad (3.2\text{-}5)$$

Here the altitude, h, is specified in metres.

(c) Determination of Air Density

Below the tropopause, the air density, ρ, in kg/m3 is calculated as function of temperature as follows:

$$\boxed{\rho = \rho_0 \left[\frac{T}{T_0}\right]^{-\frac{g}{K_T R}-1}} \qquad -\frac{g}{K_T R}-1 \approx 4.25583 \qquad (3.2\text{-}6)$$

where,

R	is the real gas constant for air, $R = 287.05287\ m^2/Ks^2$
g	is the gravitational acceleration, $g = 9.80665\ m/s^2$
k_T	is the ISA temperature gradient with altitude below the tropopause, $k_T = -0.0065$ °K/m

Here ρ_0 is the air density at sea level:

$$\rho_0 = (\rho_0)_{ISA}\,(T_0)_{ISA} / T_0 \qquad (3.2\text{-}7)$$

and $(\rho_0)_{ISA}$ is the standard atmosphere air density at sea level:

$$(\rho_0)_{ISA} = 1.225\ kg/m^3 \qquad (3.2\text{-}8)$$

Above the tropopause, the air density, ρ, in kg/m^3 is calculated as follows [RD4]:

$$\boxed{\rho = \rho_{Trop} \cdot e^{-\left(\frac{g}{R \cdot T_{Trop}}\right)\cdot(h - h_{trop})}} \qquad (3.2\text{-}9)$$

Here h represents the altitude in metres.

(d) Determination of Speed of Sound

Above the tropopause the speed of sound, a, is a constant:

$$\boxed{a_{trop} = \sqrt{\gamma \, R \, T_{trop}}}$$

where:

$\gamma = 1.4$

$R = 287.05287 \; m^2 / Ks^2$

$T_{trop} = 216.65 \; °K$

leads to

$$a_{trop} = 295.07 \;\; m/s \qquad (3.2\text{-}10)$$

Below the tropopause, the speed of sound is calculated as a function of temperature:

$$a \; = \; 340.29\sqrt{\frac{T}{(T_0)_{ISA}}} \qquad (3.2\text{-}11)$$

(e) CAS/TAS Conversion

The true air speed, V_{TAS}, is calculated as a function of the calibrated air speed, V_{CAS}, as follows:

$$\boxed{V_{TAS} \; = \left[\frac{2}{\mu}\frac{P}{\rho}\left\{\left(1+\frac{(P_0)_{ISA}}{P}\left[\left(1+\frac{\mu}{2}\frac{(\rho_0)_{ISA}}{(P_0)_{ISA}}V_{CAS}{}^2\right)^{1/\mu}-1\right]\right)^{\mu}-1\right\}\right]^{1/2}} \qquad (3.2\text{-}12)$$

Similarly, V_{CAS} is calculated as a function of V_{TAS} as follows:

$$\boxed{V_{CAS} \; = \left[\frac{2}{\mu}\frac{(P_0)_{ISA}}{(\rho_0)_{ISA}}\left\{\left(1+\frac{P}{(P_0)_{ISA}}\left[\left(1+\frac{\mu}{2}\frac{\rho}{P}V_{TAS}{}^2\right)^{1/\mu}-1\right]\right)^{\mu}-1\right\}\right]^{1/2}} \qquad (3.2\text{-}13)$$

where symbols not previously defined are explained below:

$$\boxed{\mu = \frac{(\gamma - 1)}{\gamma}} \qquad (\mu = 1 / 3.5 \;\text{ if }\; \gamma = 1.4) \qquad (3.2\text{-}14)$$

γ	is the isentropic expansion coefficient for air = 1.4	[dimensionless]
P	is the pressure at altitude	[Pa]

$(P_0)_{ISA}$ is the ISA pressure at sea level = 101325 Pa

Also note that for these conversion formulas above, the speeds V_{TAS} and V_{CAS} must be specified in m/s.

The pressure at altitude, P, can be determined from the temperature at altitude, T, by the following formula, which is valid for altitudes below the tropopause:

$$\boxed{P = (P_0)_{ISA} \cdot \left(\frac{T}{T_0}\right)^{-\frac{g}{K_T R}}} \qquad -\frac{g}{K_T \cdot R} \approx 5.25583 \tag{3.2-15}$$

where,

R	is the real gas constant for air, R = 287.05287 m^2/Ks^2
g	is the gravitational acceleration, g = 9.80665 m/s^2
k_T	is the ISA temperature gradient with altitude below the tropopause, k_T = -0.0065 °k/m

For altitudes above the tropopause, the following formula should be used:

$$\boxed{P = P_{Trop} \cdot e^{-\left(\frac{g}{R \cdot T_{Trop}}\right) \cdot (h - h_{trop})}} \tag{3.2-16}$$

where h represents the altitude in metres.

(f) Mach/TAS conversion

$$\boxed{V_{TAS} = M \times \sqrt{\gamma \cdot R \cdot T}} \tag{3.2-17}$$

where,

M	is the Mach number,
T	is the local temperature at altitude,
R	is the universal gas constant for air = 287.05287 [m^2/Ks^2]
γ	is the isentropic expansion coefficient for air = 1.4

(g) Mach/CAS transition altitude

The transition altitude (also called crossover altitude), h_{trans} (feet), between a given CAS, V_{CAS} (m/s) and a Mach number, M, is defined to be the altitude at which V_{CAS} and M represent the same TAS value, and can be calculated as follows:

$$\boxed{h_{trans} = \left(\frac{1000}{(.3048) \cdot (6.5)}\right) \cdot \left[T_0 \cdot (1 - \theta_{trans})\right]} \tag{3.2-18}$$

where,

T_0 is the temperature at sea level in Kelvin,

$(T_0)_{ISA}$ is the ISA temperature at sea level = 288.15 K,

θ_{trans} is the temperature ratio at the transition altitude,

$$\boxed{\theta_{trans} = (\delta_{trans})^{-\frac{K_T \cdot R}{g}}} \tag{3.2-19}$$

where,

R is the real gas constant for air, R = 287.05287 m^2/Ks^2

g is the gravitational acceleration, g = 9.80665 m/s^2

k_T is the ISA temperature gradient with altitude below the tropopause, k_T = -0.0065 °K/m

δ_{trans} is the pressure ratio at the transition altitude,

$$\boxed{\delta_{trans} = \frac{\left[1+\left(\frac{\gamma-1}{2}\right)\left(\frac{V_{CAS}}{(a_0)_{ISA}}\right)^2\right]^{\frac{\gamma}{\gamma-1}}-1}{\left[1+\frac{\gamma-1}{2}M^2\right]^{\frac{\gamma}{\gamma-1}}-1}} \tag{3.2-20}$$

where $(a_0)_{ISA}$ is the ISA speed of sound at sea level = 340.29 $m.s^{-1}$

3.3. AIRCRAFT TYPE

Three values are specified for aircraft type, these being the number of engines, n_{eng}, the engine type and the wake category.

The engine type can be one of three values:

- Jet,
- Turboprop, or,
- Piston.

The wake category can also be one of three values:

H - heavy
M - medium
L - light

Note that ICAO associates a wake category with each aircraft type designator [RD2].

3.4. MASS

Four mass values are specified for each aircraft in tonnes:

m_{min} - minimum mass
m_{max} - maximum mass
m_{ref} - reference mass
m_{pyld} - maximum payload mass

Note that the specified mass limits are taken from aircraft performance reference data which is available in the BADA library. In function of specific aircraft certified limitations, a particular aircraft version of a given aircraft type (model) may have different limits. More details on the way the mass limits are selected in BADA is provided in [RD6].

Aircraft operating speeds vary with the aircraft mass. This variation is calculated according to the formula below:

$$\boxed{V = V_{ref} \times \sqrt{\frac{m}{m_{ref}}}} \qquad (3.4\text{-}1)$$

In this formula, the aircraft reference speed V_{ref} is given for the reference mass m_{ref}. The speed at another mass, m, is then calculated as V.

An example of an aircraft speed, which can be calculated via this formula is the stall speed, V_{stall}.

3.5. FLIGHT ENVELOPE

(a) Maximum Speed and Altitude

The maximum speed and altitude for the aircraft are expressed in terms of the following six parameters:

V_{MO} - maximum operating speed (CAS), in knots
M_{MO} - maximum operational Mach number
h_{MO} - maximum operational height, in feet above sea level
h_{max} - maximum altitude at MTOW under ISA conditions (allowing about 300 fpm of residual ROC), in feet above sea level
G_W - mass gradient on maximum altitude, in feet/kg
G_t - temperature gradient on maximum altitude, in feet/degree Celsius

The maximum altitude for any given mass is:

$$\boxed{h_{max/act} = \mathrm{MIN}[\,h_{MO}\,, h_{max} + G_t \times (\Delta T_{ISA} - C_{Tc,4}) + G_w \times (m_{max} - m_{act})\,]} \qquad (3.5\text{-}1)$$

with: $G_W \geq 0$;
$G_t \leq 0$;
if $(\Delta T_{ISA} - C_{Tc,4}) < 0$, then : $(\Delta T_{ISA} - C_{Tc,4}) = 0$;

with ΔT_{ISA} being the temperature deviation from ISA and m_{act} being the actual aircraft mass (kg). Formula 3.5-1 should not be executed when the h_{max} value in the OPF file is set to 0 (zero). In that case the maximum altitude is always h_{MO}.

Note that the given speed and altitude limits are taken from available reference data: depending upon specific certifications, a particular aircraft of a given type may present different limits.

(b) <u>Minimum Speed</u>

The minimum speed for the aircraft is specified as follows:

$$\boxed{V_{min} = C_{Vmin,TO} \times V_{stall}} \quad \text{if in take-off} \tag{3.5-2}$$

$$\boxed{V_{min} = C_{Vmin} \times V_{stall}} \quad \text{otherwise} \tag{3.5-3}$$

Note: See 3.6.2 for minimum speed at high altitude for jet aircraft and Section 5.7 for the values of the minimum speed coefficients.

Here the speeds are specified in terms of CAS. The stall speed depends upon the configuration.

Specifically, five different configurations are specified with a stall speed [$(V_{stall})_i$] and configuration threshold altitude [$H_{max,\ i}$] given for each:

TO - take-off configuration $(V_{stall})_{TO}$
(in climb up to $H_{max,\ TO}$ AGL)

IC - initial climb configuration $(V_{stall})_{IC}$
(in climb between $H_{max,\ TO}$ and $H_{max,\ IC}$ AGL)

CR - cruise (clean) configuration $(V_{stall})_{CR}$
(in climb above $H_{max,\ IC}$ AGL,
in descent above $H_{max,\ AP}$,
in descent below $H_{max,\ AP}$ as long as
$V \geq Vmin_{Cruise} + 10$ kts)

AP - approach configuration $(V_{stall})_{AP}$
(in descent between $H_{max,\ AP}$ and $H_{max,\ LD}$ when
$V < Vmin_{Cruise} + 10$ kts,
in descent below $H_{max,\ LD}$ as long as
$V \geq Vmin_{Approach} + 10$ kts)

LD - landing configuration $(V_{stall})_{LD}$
(in descent below $H_{max,\ LD}$ when

$V < Vmin_{Approach}$ + 10 kts)

The values of the configuration threshold altitudes [$H_{max,i}$] are listed in Section 5.6. The speeds [V] used during the descent, approach and landing phases are defined in Section 4.3.

Note that these stall speeds correspond to a minimum stall speed and not a 1-g stall speed. Also, the BADA model assumes that for any aircraft these stall speeds have the following relationship:

$$\boxed{(V_{stall})_{CR} \geq (V_{stall})_{IC} \geq (V_{stall})_{TO} \geq (V_{stall})_{AP} \geq (V_{stall})_{LD}}$$

3.6. AERODYNAMICS

3.6.1. Aerodynamic Drag

The lift coefficient, C_L, is determined assuming that the flight path angle is zero. However, a correction for a bank angle is made.

$$\boxed{C_L = \frac{2 \cdot m \cdot g}{\rho \cdot V_{TAS}^{\ 2} \cdot S \cdot \cos\phi}} \tag{3.6-1}$$

Under nominal conditions, the drag coefficient, C_D is specified as a function of the lift coefficient C_L as follows:

$$\boxed{C_D = C_{D0,CR} + C_{D2,CR} \times (C_L)^2} \tag{3.6-2}$$

Formula 3.6-2 is valid for all situations except for the approach and landing where other drag coefficients are to be used.

In the approach configuration (as defined in Section 3.5) a different flap setting is used, and formula 3.6-3 should be applied:

$$\boxed{C_D = C_{D0,AP} + C_{D2,AP} \times (C_L)^2} \tag{3.6-3}$$

In the landing configuration (as defined in Section 3.5) a different flap setting is used, and formula 3.6-4 should be applied:

$$\boxed{C_D = C_{D0,LDG} + C_{D0,\Delta LDG} + C_{D2,LDG} \times (C_L)^2} \tag{3.6-4}$$

The value of $C_{D0,\ \Delta LDG}$ represents drag increase due to the landing gear. The values of $C_{D0,\ LD}$ in the OPF files were all determined for the landing flap setting mentioned in the OPF file.

The drag force (in Newtons) is then determined from the drag coefficient in the standard manner:

$$\boxed{D = \frac{C_D \cdot \rho \cdot V_{TAS}^{\ 2} \cdot S}{2}} \tag{3.6-5}$$

Where :

ρ is the air density (kg/m^3)

S is the wing reference area (m^2)

V_{TAS} is the true airspeed (m/s).

Note that the air density is a function of altitude as described in subsection 3.2.

The above equations thus result in eight coefficients for the specification of drag:

S	
$C_{D0,CR}$	$C_{D2,CR}$
$C_{D0,AP}$	$C_{D2,AP}$
$C_{D0,LD}$	$C_{D2,LD}$
$C_{D0,\Delta LDG}$	

In case the CD0,AP , CD2,AP , CD0,LD , CD2,LD and CD0,ΔLDG coefficients (referred to as “non-clean” data in this document) are set to 0 (zero) in the OPF file, expression 3.6-2 will be used in all cases.

3.6.2. Low Speed Buffeting Limit (jet aircraft only)

For jet aircraft a low speed buffeting limit has been introduced. This buffeting limit is expressed as a Mach number and can be determined using the following equation:

$$\boxed{k \times M^3 - C_{Lbo\,(M=0)} \times M^2 + \frac{W}{S \cdot P \cdot 0.583} = 0} \qquad (3.6\text{-}6)$$

where:

k is lift coefficient gradient

$C_{Lbo\,(M=0)}$ is initial buffet onset lift coefficient for M=0

P is actual pressure (Pa)

M is Mach number

S is the wing reference area (m^2)

W is aircraft weight (N)

Note that the factor of 0.583 gives a 0.2 g margin.

The k and $C_{Lbo\,(M=0)}$ parameters have been determined for nearly all jet aircraft in BADA 3.7. If the k and $C_{Lbo\,(M=0)}$ parameters in the OPF file are set to 0 (zero), the minimum speed is given by expressions 3.5-2 and 3.5-3. Otherwise, the solution for M in Formula 3.6-6 can be obtained using the method given in Appendix B. The buffeting limit should be applied as a minimum speed in the following way:

- If (Altitude > 15,000 ft) then: $V_{min} = MAX(V_{min,stall}, M_b)$

- If (Altitude < 15,000 ft) then: $V_{min} = V_{min,stall}$

where: M_b is the lowest positive solution of expression 3.6-6,

$V_{min,stall}$ is given by expressions 3.5-2 and 3.5-3

Note that the units of the two values ($V_{min,stall}$ and M_b) inside the MAX() expression should be the same.

3.7. ENGINE THRUST

The BADA model provides coefficients that allow the calculation of the following thrust levels:

- maximum climb and take-off,
- maximum cruise,
- descent.

The thrust is calculated in Newtons and includes the contribution from all engines. The subsections below provide the equations for each of the thrust conditions.

3.7.1. Maximum Climb and Take-Off Thrust

The maximum climb thrust at standard atmosphere conditions, $(T_{max\ climb})_{ISA}$, is calculated in Newtons as a function of the following information:

- engine type: either Jet, Turboprop or Piston;
- altitude above sea level, h, in feet;
- true air speed, V_{TAS} , in knots;
- temperature deviation from standard atmosphere, ΔT_{ISA}, in degrees Celsius.

The equations corresponding to the three engine types are given below.

Jet:
$$\boxed{(T_{max\ climb})_{ISA} = C_{Tc,1} \times \left(1 - \frac{h}{C_{Tc,2}} + C_{Tc,3} \times h^2\right)} \quad (3.7\text{-}1)$$

Turboprop:
$$\boxed{(T_{max\ climb})_{ISA} = C_{Tc,1} \times \left(1 - \frac{h}{C_{Tc,2}}\right) \Big/ V_{TAS} + C_{Tc,3}} \quad (3.7\text{-}2)$$

Piston:
$$\boxed{(T_{max\ climb})_{ISA} = C_{Tc,1} \times \left(1 - \frac{h}{C_{Tc,2}}\right) + \frac{C_{Tc,3}}{V_{TAS}}} \quad (3.7\text{-}3)$$

For all engine types, the maximum climb thrust is corrected for temperature deviations from standard atmosphere, ΔT_{ISA} , in the following manner:

$$\boxed{T_{max\ climb} = (T_{max\ climb})_{ISA} \times \left(1 - C_{Tc,5} \cdot (\Delta T_{ISA})_{eff}\right)} \quad (3.7\text{-}4)$$

Where:

$$(\Delta T_{ISA})_{eff} = \Delta T_{ISA} - C_{Tc,4} \quad (3.7\text{-}5)$$

with the limits:

$$0.0 \le (\Delta T_{ISA})_{eff} \times C_{Tc,5} \le 0.4 \quad (3.7\text{-}6)$$

and:

$$C_{Tc,5} \ge 0.0 \quad (3.7\text{-}7)$$

This maximum climb thrust is used for both take-off and climb phases.

3.7.2. Maximum Cruise Thrust

The normal cruise thrust is by definition set equal to drag (T = D). However, the maximum amount of thrust available in cruise situation is limited. The maximum cruise thrust is calculated as a ratio of the maximum climb thrust given by expression 3.7-4, that is:

$$\boxed{(T_{cruise})_{MAX} = C_{Tcr} \times T_{max\ climb}} \tag{3.7-8}$$

The coefficient C_{Tcr} is currently uniformly set for all aircraft (see Global Aircraft Parameters section 5.5).

3.7.3. Descent Thrust

Descent thrust is calculated as a ratio of the maximum climb thrust given by expression 3.7-4, with different correction factors used for high and low altitudes, and approach and landing configurations (see Section 3.5), that is:

if $h > h_{des}$:

$$\boxed{T_{des,high} = C_{Tdes,high} \times T_{max\ climb}} \tag{3.7-9}$$

if $h \leq h_{des}$:

Cruise configuration:

$$\boxed{T_{des,low} = C_{Tdes,low} \times T_{max\ climb}} \tag{3.7-10}$$

Approach configuration:

$$\boxed{T_{des,app} = C_{Tdes,app} \times T_{max\ climb}} \tag{3.7-11}$$

Landing configuration:

$$\boxed{T_{des,ld} = C_{Tdes,ld} \times T_{max\ climb}} \tag{3.7-12}$$

Note that for those models where “non-clean” data (see Section 3.6.1) is available, h_{des} cannot be below $H_{max,\ AP}$.

3.8. REDUCED CLIMB POWER

The reduced climb power has been introduced to allow the simulation of climbs using less than the maximum climb setting. In day-to-day operations, many aircraft use a reduced setting during climb in order to extend engine life and save cost. The correction factors that are used to calculate the reduction in power have been obtained in an empirical way and have been validated with the help of air traffic controllers.

In BADA, climbs that are performed using the full climb power will result in profiles that match the reference data that is found in the Flight Manual of the aircraft. Climbs with reduced power will give a realistic profile.

$$\boxed{C_{pow,\,red} = 1 - C_{red} \times \frac{m_{max} - m_{act}}{m_{max} - m_{min}}} \qquad (3.8\text{-}1)$$

The value of C_{red} is a function of the aircraft type and is given in Section 5.11.

Nevertheless:

If $h < (0.8 * h_{max})$:

$C_{red} = f$ (aircraft type) (see Section 5.11)

Else

$C_{red} = 0$ [dimensionless]

where h_{max} is given by expression 3.5-1.

The power reduction $C_{pow,red}$ is to be applied during the climb phase in expression 3.1-4, which becomes:

$$\boxed{\frac{dh}{dt} = \left[\frac{(T_{max,climb} - D) \times V_{TAS} \times C_{pow,red}}{mg}\right] f\{M\}} \quad \text{(in climb)} \qquad (3.8\text{-}2)$$

3.9. FUEL CONSUMPTION

3.9.1. Jet and Turboprop Engines

For the jet and turboprop engines, the thrust specific fuel consumption, η (kg/(min*kN)), is specified as a function of true airspeed, V_{TAS} (knots):

jet: $$\boxed{\eta = C_{f1} \times \left(1 + \frac{V_{TAS}}{C_{f2}}\right)} \qquad (3.9\text{-}1)$$

turboprop: $$\boxed{\eta = C_{f1} \times \left(1 - \frac{V_{TAS}}{C_{f2}}\right) \times \left(V_{TAS}/1000\right)} \qquad (3.9\text{-}2)$$

The nominal fuel flow, f_{nom} (kg/min), can then be calculated using the thrust, T:

jet/turboprop: $$\boxed{f_{nom} = \eta \times T} \qquad (3.9\text{-}3)$$

These expressions are used in all flight phases except during idle descent and cruise, where the following expressions are to be used.

Minimum fuel flow, f_{min} (kg/min), corresponding to idle thrust descent conditions for both jet and turboprop engines, is specified as a function of altitude above sea level, h (ft), that is:

jet/turboprop: $$\boxed{f_{min} = C_{f3}\left(1 - \frac{h}{C_{f4}}\right)} \qquad (3.9\text{-}4)$$

Note that for both jet and turboprop engines, the idle thrust part of the descent stops when the aircraft switches to approach and landing configuration (see Section 3.5). Hence, the expressions 3.7-11, 3.7-12 and 3.9-3 are used for calculation of fuel flow during approach and landing phases.

Cruise fuel flow, f_{cr} (kg/min), is calculated using the thrust specific fuel consumption η, the thrust T, and a cruise fuel flow factor, C_{fcr}:

jet/turboprop: $$\boxed{f_{cr} = \eta \times T \times C_{fcr}} \qquad (3.9\text{-}5)$$

For the moment the cruise fuel flow correction factor has been established for a number of aircraft types whenever the reference data for cruise fuel consumption is available. This factor has been set to 1 (one) for all the other aircraft models.

3.9.2. Piston Engines

For piston engines, the nominal fuel flow, f_{nom} (kg/min), is specified to be a constant, that is:

$$\boxed{f_{nom} = C_{f1}} \qquad (3.9\text{-}6)$$

This expression is used in all flight phases except during descent and cruise, where the following expressions are to be used.

Minimum fuel flow, f_{min} (kg/min), corresponding to descent conditions for piston engines, is specified to be a constant:

$$\boxed{f_{min} = C_{f3}} \qquad (3.9\text{-}7)$$

Cruise fuel flow, f_{cr} (kg/min), is calculated using a cruise fuel flow factor, C_{fcr}:

$$\boxed{f_{cr} = C_{f1} \times C_{fcr}} \qquad (3.9\text{-}8)$$

For the moment the cruise fuel flow correction factor has been established for a number of aircraft types whenever the reference data for cruise fuel consumption is available. This factor has been set to 1 (one) for all the other aircraft models.

3.10. GROUND MOVEMENT

Four values are specified that can be of use when simulating ground movements. These parameters are:

- TOL: - FAR Take-Off Length with MTOW on a dry, hard, level runway under ISA conditions and no wind [m].
- LDL: - FAR Landing Length with MLW on a dry, hard, level runway under ISA conditions and no wind [m].
- span: - Aircraft wingspan [m]
- length: - Aircraft length [m]

Note that currently the value of the MLW is not provided in BADA. Apart from these model specific parameters, there are also a number of ground speeds defined as general parameters in Section 5.10.

3.11. SUMMARY OF OPERATIONS PERFORMANCE PARAMETERS

A summary of the parameters specified by the BADA operations performance model is supplied in Table 3.11-1 below. This table excludes those parameters that have been set to zero.

Detailed information on how these parameters have been obtained during the process of BADA aircraft model identification using the aircraft performance reference documents is provided in [RD6].

Important notice: Parameters listed in bold in the Table 3-1 below should not be modified by the user as such modifications may impact the validity of the data provided in [RD13].

Table 3-1: BADA Operations Performance Parameter Summary

Model Category	Symbols	Units	Description
aircraft type (3 values)	**n_{eng}** **engine type** **wake category**	dimensionless string string	**number of engines** **either Jet, Turboprop or Piston** **either H (heavy), M (medium) or L (light)**
mass (4 values) see def. P25	**m_{ref}** **m_{min}** **m_{max}** **m_{pyld}**	tonnes tonnes tonnes tonnes	**reference mass** **minimum mass** **maximum mass** **maximum payload mass**
flight envelope (6 values)	**V_{MO}** **M_{MO}** **h_{MO}** **h_{max}** **G_w** **G_t**	knots (CAS) dimensionless feet feet feet/kg feet/C	**maximum operating speed** **maximum operating Mach number** **maximum operating altitude** **max. altitude at MTOW and ISA** **weight gradient on max. altitude** **temperature gradient on max. altitude**
Aerodynamics (14 values) (16 values for jet aircraft)	**S** **$C_{D0,CR}$** **$C_{D2,CR}$** **$C_{D0,AP}$** **$C_{D2,AP}$** **$C_{D0,LD}$** **$C_{D2,LD}$** **$C_{D0,\Delta LDG}$**	m2 dimensionless dimensionless dimensionless dimensionless dimensionless dimensionless dimensionless knots (CAS)	**reference wing surface area** **parasitic drag coefficient (cruise)** **induced drag coefficient (cruise)** **parasitic drag coefficient (approach)** **induced drag coefficient (approach)** **parasitic drag coefficient (landing)** **induced drag coefficient (landing)** **parasite drag coef. (landing gear)** **stall speed [TO, IC, CR, AP, LD]**

Model Category	Symbols	Units	Description
	$(V_{stall})i$ **$C_{Lbo(M=0)}$** **K**	Dimensionless [1/M]	**Buffet onset lift coef. (jet only)** **Buffeting gradient (jet only)**
engine thrust (12 values)	**$C_{Tc,1}$**	Newton (jet/piston) knot-Newton (turboprop)	**1st max. climb thrust coefficient**
	$C_{Tc,2}$	feet	**2nd max climb thrust coefficient**
	$C_{Tc,3}$	1/feet2 (jet) Newton (turboprop) knot-Newton (piston)	**3rd max. climb thrust coefficient**
	$C_{Tc,4}$	deg. C	**1st thrust temperature coefficient**
	$C_{Tc,5}$	1/ deg. C	**2nd thrust temperature coefficient**
	$C_{Tdes,low}$	dimensionless	**low altitude descent thrust coefficient**
	$C_{Tdes,high}$	dimensionless	**high altitude descent thrust coefficient**
	h_{des}	feet	**transition altitude for calculation of descent thrust**
	$C_{Tdes, app}$	dimensionless	**approach thrust coefficient**
	$C_{Tdes,ld}$	dimensionless	**landing thrust coefficient**
	$V_{des,ref}$	knots	reference descent speed (CAS)
	$M_{des,ref}$	Dimensionless	reference descent Mach number
fuel flow (5 values)	**C_{f1}**	kg/(min*kN) (jet) kg/(min*kN*knot) (turboprop) kg/min (piston)	**1st thrust specific fuel consumption coefficient**
	C_{f2}	knots	**2nd thrust specific fuel consumption coefficient**
	C_{f3}	kg/min	**1st descent fuel flow coefficient**
	C_{f4}	feet	**2nd descent fuel flow coefficient**
	C_{fcr}	dimensionless	**Cruise fuel flow correction coefficient**
Ground movement (4 values)	TOL	m	take-off length
	LDL	m	landing length
	span	m	wingspan
	length	m	Length

4. AIRLINE PROCEDURE MODELS

This section defines the standard airline procedures, which are parameterised by the BADA airline procedure models. Definition of the standard airline procedures in BADA is driven by a requirement to provide means of simulating standard or nominal aircraft operations using different simulation and modelling tools for various ATM applications.

The BADA airline procedure model is provided for three separate flight phases: climb, cruise and descent. For each of these phases and each aircraft model, the BADA airline procedure model requires the following information to determine aircraft speed schedule:

1. BADA airline procedure default speeds provided in Airline Procedure File (APF):

   V_1 - standard CAS (knots) below 10,000 ft;

   V_2 - standard CAS (knots) between 10,000 ft and Mach transition altitude;

   M - standard Mach number above Mach transition altitude;

   where the Mach transition altitude is defined in Section 3.2 (g).

2. Stall speeds for take-off and landing configurations provided in Operations Performance File (OPF)
3. Coefficients provided in the Section 5.7 and 5.8

The process of definition of the BADA airline procedure default speeds and choice of aircraft configurations in function of flight phase is described in [RD6]. The airline procedure model below 10,000 ft with corresponding coefficients (mentioned under item 3 above) have been defined taking into account aircraft manufacturer's performance reference data and aircraft operational data available at EUROCONTROL.

The fact that the way aircraft is operated varies significantly in function of specific airspace procedures and operating policies of locally dominant airlines is widely recognised. It is for that reason that the resulting speed schedules of the BADA standard airline procedure model may differ from a geographical location or of an aerospace's specific aircraft operation.

To account for the local aircraft operation characteristics and improve conformance of the simulated aircraft behaviour with real operations, the user of BADA is given a possibility to modify the BADA default speeds (as provided in APF file). The change of speed related APF parameters should be done in accordance with the BADA modelling procedure described in the Chapter 2.2.3 of [RD6].

However, the stall speeds (as provided in OPF file) and coefficients detailed in Section 5.7 and 5.8 are not subject to modification. The BADA User should not modify them.

4.1. CLIMB

The following parameters are defined for each aircraft type to characterise the climb phase:

$V_{cl,1}$ - standard climb CAS (knots) between 1,500 / 6,000 and 10,000 ft.

$V_{cl,2}$ - standard climb CAS (knots) between 10,000 ft and Mach transition altitude.

M_{cl} - standard climb Mach number above Mach transition altitude.

Note that the climb speed schedule shall determine an increasing speed from takeoff to $V_{cl,1}$. To ensure that monotony, it is recommended to determine the speed schedule from the highest altitude to the lowest one, and to use at each step the speed of the higher altitude range as a ceiling value for the lower altitude range.

- For jet aircraft the following CAS schedule is assumed, based on the parameters mentioned above and the take-off stall speed:

from 0 to 1,499 ft	$C_{Vmin}* (V_{stall})_{TO} + Vd_{CL,1}$	(4.1-1)
from 1,500 to 2,999 ft	$C_{Vmin}* (V_{stall})_{TO} + Vd_{CL,2}$	(4.1-2)
from 3,000 to 3,999 ft	$C_{Vmin}* (V_{stall})_{TO} + Vd_{CL,3}$	(4.1-3)
from 4,000 to 4,999 ft	$C_{Vmin}* (V_{stall})_{TO} + Vd_{CL,4}$	(4.1-4)
from 5,000 to 5,999 ft	$C_{Vmin}* (V_{stall})_{TO} + Vd_{CL,5}$	(4.1-5)
from 6,000 to 9,999 ft	min ($V_{cl,1}$, 250 kt)	
from 10,000 ft to Mach transition altitude	$V_{cl,2}$	
above Mach transition altitude	M_{cl}	

- For turboprop and piston aircraft the following CAS schedule is assumed:

from 0 to 499 ft	$C_{Vmin}* (V_{stall})_{TO} + Vd_{CL,6}$	(4.1-6)
from 500 to 999 ft	$C_{Vmin}* (V_{stall})_{TO} + Vd_{CL,7}$	(4.1-7)
from 1,000 to 1,499 ft	$C_{Vmin}* (V_{stall})_{TO} + Vd_{CL,8}$	(4.1-8)
from 1,500 to 9,999 ft	min ($V_{cl,1}$, 250 kt)	
from 10,000 ft to Mach transition altitude	$V_{cl,2}$	
above Mach transition altitude	M_{cl}	

The take-off stall speed, $(V_{stall})_{TO}$, must be corrected for the difference in aircraft mass from the reference mass using formula 3.4-1. The values for $Vd_{CL,i}$ can be found in Section 5.

4.2. CRUISE

The following parameters are defined for each aircraft type to characterise the cruise phase:

$V_{cr,1}$	-	standard cruise CAS (knots) between 3,000 and 10,000 ft
$V_{cr,2}$	-	standard cruise CAS (knots) between 10,000 ft and Mach transition altitude
M_{cr}	-	standard cruise Mach number above Mach transition altitude

- For jet aircraft the following CAS schedule is assumed:

from 0 to 2,999 ft	170 kt
from 3,000 to 5,999 ft	min ($V_{cr,1}$, 220 kt)
from 6,000 to 13,999 ft	min ($V_{cr,1}$, 250 kt)
from 14,000 ft to Mach transition altitude	$V_{cr,2}$
above Mach transition altitude	M_{cr}

- For turboprop aircraft the following CAS schedule is assumed:

from 0 to 2,999 ft	150 kt
from 3,000 to 5,999 ft	min ($V_{cr,1}$, 180 kt)
from 6,000 to 9,999 ft	min ($V_{cr,1}$, 250 kt)
from 10,000 ft to Mach transition altitude	$V_{cr,2}$
above Mach transition altitude	M_{cr}

4.3. DESCENT

The following parameters are defined for each aircraft type to characterise the descent phase:

$V_{des,1}$	-	standard descent CAS (knots) between 3,000 / 6,000 and 10,000 ft.
$V_{des,2}$	-	standard descent CAS (knots) between 10,000 ft and Mach transition altitude.
M_{des}	-	standard descent Mach number above Mach transition altitude.

Note that the descent speed schedule shall determine a decreasing speed from $V_{des,1}$ to landing. To ensure that monotony, it is recommended to evaluate the speed schedule from the highest altitude to the lowest one, and to use at each step the speed of the higher altitude range as a ceiling value for the lower altitude range.

- For jet and turboprop aircraft the following CAS schedule is assumed, based on the above parameters and the landing stall speed:

from 0 to 999 ft	C_{Vmin}* $(V_{stall})_{LD}$ + $Vd_{DES,\,1}$	(4.3-1)
from 1,000 to 1,499 ft	C_{Vmin}* $(V_{stall})_{LD}$ + $Vd_{DES,\,2}$	(4.3-2)
from 1,500 to 1,999 ft	C_{Vmin}* $(V_{stall})_{LD}$ + $Vd_{DES,\,3}$	(4.3-3)
from 2,000 to 2,999 ft	C_{Vmin}* $(V_{stall})_{LD}$ + $Vd_{DES,\,4}$	(4.3-4)
from 3,000 to 5,999 ft	min ($V_{des,1}$, 220)	
from 6,000 to 9,999 ft	min ($V_{des,1}$, 250)	
from 10,000 ft to Mach transition altitude	$V_{des,2}$	
above Mach transition altitude	M_{des}	

- For piston aircraft the following CAS schedule is assumed:

from 0 to 499 ft	C_{Vmin}* $(V_{stall})_{LD}$ + $Vd_{DES,\,5}$	(4.3-5)
from 500 to 999 ft	C_{Vmin}* $(V_{stall})_{LD}$ + $Vd_{DES,\,6}$	(4.3-6)
from 1000 to 1,499 ft	C_{Vmin}* $(V_{stall})_{LD}$ + $Vd_{DES,\,7}$	(4.3-7)
from 1,500 to 9,999 ft	$V_{des,1}$	
from 10,000 ft to Mach transition altitude	$V_{des,2}$	
above Mach transition altitude	M_{des}	

The landing stall speed, $(V_{stall})_{LD}$, must be corrected for the difference in aircraft mass from the reference mass using formula 3.4-1. The values for $Vd_{DES,i}$ can be found in Section 5.

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5. GLOBAL AIRCRAFT PARAMETERS

5.1. INTRODUCTION

A number of parameters that have been described in Section 3 (Operations Performance Model) and Section 4 (Airline Procedure Model) have values that are independent of the aircraft type or model for which they are used. The values of these and other parameters that up to BADA 2.4 were hard-coded in the aircraft navigator (MASS at the EEC), have been put in the General Parameters File (BADA.GPF). This increases the flexibility and allows an easier evaluation of the values that are used.

The next section gives an overview of the parameters that are defined in the Global Parameters File. If relevant, it also indicates the formula in which the parameter should be used.

5.2. MAXIMUM ACCELERATION

Maximum acceleration parameters are used to limit the increment in TAS (longitudinal) or ROCD (normal). 2 parameters are defined:

Name:	**Description:**	**Value [fps^2]:**
$a_{l,\ max\ (civ)}$	maximum longitudinal acceleration for civil flights	2.0
$a_{n,\ max\ (civ)}$	maximum normal acceleration for civil flights	5.0

The two acceleration limits are to be used in the following way:

- longitudinal acceleration: $\left| V_k - V_{k-1} \right| \leq a_{l\,max\,(civ)}\ \Delta t$ (5.2-1)
- normal acceleration: $\left| \gamma_k - \gamma_{k-1} \right| \leq \dfrac{a_{n\,max\,(civ)}\ \Delta t}{V}$ (5.2-2)

where,

$$\gamma = \sin^{-1}\left(\frac{\dot{h}}{V}\right) \quad (5.2\text{-}3)$$

and,

γ	is the climb/descent angle,
V	is the True Air Speed,
k, $k-1$	indicates values at update intervals k and k-1,and,
Δt	is the time interval between k and k-1

The values for $a_{l,\ max\ (mil)}$ (maximum longitudinal acceleration for military flights) and $a_{n,\ max\ (mil)}$ (maximum normal acceleration for military flights) are currently undefined.

5.3. BANK ANGLES

Nominal and maximum bank angles are defined separately for military and civil flights. These bank angles can be used to calculate nominal and maximum rate of turns.

Name:	Description:	Value [degr.]:
$\phi_{nom,\ civ\ (TO,\ LD)}$	Nominal bank angles for civil flight during TO and LD	15
$\phi_{nom,\ civ\ (OTHERS)}$	Nominal bank angles for civil flight during all other phases	35
$\phi_{nom,\ mil}$	Nominal bank angles for military flight (all phases)	50
$\phi_{max,\ civ\ (TO,\ LD)}$	Maximum bank angles for civil flight during TO and LD	25
$\phi_{max,\ civ\ (HOLD)}$	Maximum bank angles for civil flight during HOLD	35
$\phi_{max,\ civ\ (OTHERS)}$	Maximum bank angles for civil flight during all other phases	45
$\phi_{max,\ mil}$	Maximum bank angles for military flight (all phases)	70

The rate of turn ($\dot{\varphi}$) is calculated as a function of bank angle:

$$\dot{\varphi} = \frac{g}{V_{TAS}} \times \tan(\phi) \quad (5.3\text{-}1)$$

5.4. EXPEDITED DESCENT

The expedited descent factor is to be used as a drag multiplication factor during expedited descents in order to simulate use of spoilers:

Name:	Description:	Value [-]:
$C_{des,\ exp}$	Expedited descent factor	1.6

The drag during an expedited descent is calculated using the nominal drag (see 3.6.1):

$$D_{des,\ exp} = C_{des,\ exp} * D_{nom} \quad (5.4\text{-}1)$$

5.5. THRUST FACTORS

Maximum take-off and maximum cruise thrust factors have been specified. The $C_{Th,TO}$ factor is no longer used since BADA 3.0. The C_{Tcr} factor is to be used in expression 3.7-8.

Name:	Description:	Value [-]:
$C_{Th,TO}$	Take-off thrust coefficient	1.2
C_{Tcr}	Maximum cruise thrust coefficient	0.95

5.6. CONFIGURATION ALTITUDE THRESHOLD

For 4 configurations, altitude thresholds have been specified in BADA: take-off (TO), initial climb (IC), approach (AP) and landing (LD). Note that the selection of the take-off and initial climb configurations is defined only with the altitude. The selection of the approach and landing configurations is done through the use of air speed and altitude (see Section 3.5), while the altitudes at which the configuration change takes place should not be higher than the ones given below.

Name:	Description:	Value [ft]:
$H_{max,\ TO}$	Maximum altitude threshold for take-off	400
$H_{max,\ IC}$	Maximum altitude threshold for initial climb	2,000
$H_{max,\ AP}$	Maximum altitude threshold for approach	8,000
$H_{max,\ LD}$	Maximum altitude threshold for landing	3,000

5.7. MINIMUM SPEED COEFFICIENTS

Two minimum speed coefficients are specified, which are to be used in expressions 3.5-2 and 3.5-3 and (for C_{Vmin} only) in Section 4.1 and 4.3:

Name:	Description:	Value [-]:
$C_{Vmin,TO}$	Minimum speed coefficient for take-off	1.2
C_{Vmin}	Minimum speed coefficient (all other phases)	1.3

5.8. SPEED SCHEDULES

The speed schedules applicable below FL100 for climb and descent are based on a factored stall speed plus increment valid for a specified altitude range:

Name:	Description:	Value[KCAS]:
$Vd_{CL,\ 1}$	Climb speed increment below 1500 ft (jet)	5
$Vd_{CL,\ 2}$	Climb speed increment below 3000 ft (jet)	10
$Vd_{CL,\ 3}$	Climb speed increment below 4000 ft (jet)	30
$Vd_{CL,\ 4}$	Climb speed increment below 5000 ft (jet)	60
$Vd_{CL,\ 5}$	Climb speed increment below 6000 ft (jet)	80
$Vd_{CL,\ 6}$	Climb speed increment below 500 ft (turbo/piston)	20
$Vd_{CL,\ 7}$	Climb speed increment below 1000 ft (turbo/piston)	30
$Vd_{CL,\ 8}$	Climb speed increment below 1500 ft (turbo/piston)	35
$Vd_{DES,\ 1}$	Descent speed increment below 1000 ft (jet/turboprop)	5
$Vd_{DES,\ 2}$	Descent speed increment below 1500 ft (jet/turboprop)	10
$Vd_{DES,\ 3}$	Descent speed increment below 2000 ft (jet/turboprop)	20
$Vd_{DES,\ 4}$	Descent speed increment below 3000 ft (jet/turboprop)	50
$Vd_{DES,\ 5}$	Descent speed increment below 500 ft (piston)	5

$Vd_{DES,\,6}$	Descent speed increment below 1000 ft (piston)	10
$Vd_{DES,\,7}$	Descent speed increment below 1500 ft (piston)	20

These values are to be used in the expressions in Section 4.1 and 4.3.

5.9. HOLDING SPEEDS

The holding speeds that are to be used to calculate holding areas are defined according to the ICAO standards:

Name:	Description:	Value[KCAS]:
$V_{hold,\,1}$	Holding speed below FL140	230
$V_{hold,\,2}$	Holding speed between FL140 and FL200	240
$V_{hold,\,3}$	Holding speed between FL200 and FL340	265
$V_{hold,\,4}$	Holding speed above FL340 [Mach]	0.83

Note that the holding speeds that are used by individual aircraft may vary between types.

5.10. GROUND SPEEDS

A number of ground speeds are defined for the simulation of ground movement. For the moment, no distinction between aircraft type or engine type is made. The following speeds have been defined:

Name:	Description:	Value[KCAS]:
$V_{backtrack}$	Runway backtrack speed	35
V_{taxi}	Taxi speed	15
V_{apron}	Apron speed	10
V_{gate}	Gate speed	5

The runway backtrack speed is the speed the aircraft will maintain when it backtracks across the runway. The taxi speed is used anywhere between the runway and the apron area. The apron speed is used in the apron area while the gate speed is used for all manoeuvring between the gate position and the apron.

5.11. REDUCED POWER COEFFICIENT

The reduced power coefficients are defined for the three different engine types. It is stressed that the values given below where found in an empirical way and have been validated with the help of air traffic controllers:

Name:	Description:	Value[-]:
$C_{red,turbo}$	Maximum reduction in power for turboprops	0.25
$C_{red,piston}$	Maximum reduction in power for pistons	0.0
$C_{red,jet}$	Maximum reduction in power for jets	0.15

The coefficients should be used in Formula 3.8-1.

6. FILE STRUCTURE

6.1. FILE TYPES

All data provided by BADA Revision 3.7 is organised into six types of files:

- three Synonym Files,
- a set of Operations Performance Files,
- a set of Airline Procedure Files,
- a set of Performance Table Files,
- a set of Performance Table Data,
- a Global Parameter File.

▪ Three Synonym Files have the names:

SYNONYM.LST
SYNONYM.NEW
SYNONYM_ALL.LST

The files provide a list of all the aircraft types which are supported by BADA and indicate whether the aircraft type is supported directly (through provision of parameters in other files) or supported by equivalence (through indicating an equivalent aircraft type that is supported directly). In addition to that, SYNONYM_ALL.LST file provides the information on history and evolution of the ICAO aircraft designators over the years. The format of the files is described in Section 6.3.

- There is one Operations Performance File (OPF) provided for each aircraft type which is directly supported. This file specifies parameter values for the mass, flight envelope, drag, engine thrust and fuel consumption that are described in Section 3. Details on the format of the OPF file are given in Section 6.4.

- There is one Airline Procedures File (APF) for each directly supported aircraft type. This file specifies the nominal manoeuvre speeds that are described in Section 4. Details on the format of the APF file are given in Section 6.5.

- There is one Performance Table File (PTF) for each directly supported aircraft type. This file contains a summary table of speeds, climb/descent rates and fuel consumption at various flight levels. Details on the format of the PTF file are given in Section 6.6.

- There is one Performance Table Data (PTD) file for each directly supported aircraft type. This file contains a detailed table of computed performance values at various flight levels. Details on the format of the PTD file are given in Section 6.7.

- Finally there is one Global Parameter File which is named BADA.GPF. This file contains parameters that are described in Section 5 and are valid for all aircraft or a group of aircraft (for instance all civil flights or all jet aircraft). Details on the format of the GPF file are given in Section 6.7.

The names of the OPF, APF, PTF and PTD files are based on the ICAO designation code for the aircraft type. With only the exception of the generic military fighter aircraft types (FGTH, FGTL, FGTN), this code is the same as the International Civil Aviation Organisation (ICAO) designator code for the aircraft type [RD2]. That is:

Operations Performance File name:	<ICAO_code>__.OPF
Airline Procedures File name:	<ICAO_code>__.APF
Performance Table File name:	<ICAO_code>__.PTF
Performance Table Data name:	<ICAO_code>__.PTD

Note that there are at least two underscore characters between the ICAO code and the file extension such that the length of the file name without the extension is six characters. Most ICAO codes are four characters in length and thus have two underscore characters. Some ICAO codes, however, can be shorter (e.g. F50) and thus require more underscore characters. For example, an Airbus 310 which has the ICAO code of A310 is represented in BADA 3.7 by the following files:

Operations Performance File:	A310__.OPF
Airline Procedures File:	A310__.APF
Performance Table File:	A310__.PTF
Performance Table Data:	A310__.PTD

The Fokker F50, which has the ICAO code of F50, is represented in BADA 3.7 by the following files:

Operations Performance File:	F50___.OPF
Airline Procedures File:	F50___.APF
Performance Table File:	F50___.PTF
Performance Table Data:	F50___.PTD

All files belonging to BADA Revision 3.7, that is the Synonym Files, the GPF file and all APF, OPF, PTF and PTD files are controlled within a configuration management system. This system is described in Section 6.2.

6.2. FILE CONFIGURATION MANAGEMENT

Starting with the BADA 3.4 release, the BADA Synonym Files, GPF and all APF, OPF, PTF and PTD files are placed and managed under the Change Management Synergy (CM Synergy) tool at EUROCONTROL.

This section briefly describes some of the CM Synergy features that will be used for the management of the BADA files.

CM Synergy provides a complete change management environment in which development and management of the files can be done easily, quickly, and securely. It maintains control of file versions and allows management of project releases with some of the benefits listed below:

- workflow management, which enables easy identification of the files modified to implement the change, and review of the reason for a change,

- project reproducibility by accurately creating baseline configurations,
- role-based security,
- Distributed Change Management (DCM) which allows files sharing among any number of CM Synergy databases. With DCM transfer of an entire database or a subset of a database can be done, either automatically or manually.

The CM Synergy automated migration facilities feature complete version history migration from RCS system archives. This has enabled to bring successfully all the BADA files with their history under the CM Synergy control. A CM Synergy database is created for BADA project. Such a database represents a data repository that stores all controlled data, including data files, their properties and relationships to one another.

The following BADA files are placed in the CM Synergy database:

- the Synonym Files
- the GPF file
- all APF, OPF, PTF and PTD files

Within the CM Synergy, different methodologies in the way the files are managed are used. For BADA database, the task-based methodology is chosen which enables the tracking of the changes by using tasks, rather than individual files, as the basic unit of work.

The specific procedures used for configuration management are specified in the BADA Configuration Management Manual [RD5].

6.2.1. File Identification

Any file managed in a CM Synergy database is uniquely identified by the following attributes: *name, version, type, and instance.* By default, the four-part name (also called full name) is written like this: *name-version:type:instanc*.

A file name can be up to 151 characters long, and the version can be any 32-character combination. The type can be any of the default types (e.g., *csrc*, *ascii*, etc.), or any BADA type that is created (APF, OPF, PTF, PTD, GPF).

The name, version, and type are designated by the user, but the instance is calculated by CM Synergy.

The version of a file corresponds to the evolution of the file in time. By default, CM Synergy creates version numbers, starting with 1, for each file that is created in the CM Synergy database. Each time the object is modified, CM Synergy increments the version.

The instance is used to distinguish between multiple objects with the same name and type, but that are not versions of each other.

It is important to notice that, following the CM Synergy approach of the file identification, no information on the file version is provided in the BADA file itself.

A new layout of the header of BADA files has been developed and it will be described in more details in the following sections.

6.2.2. History

The history of a file shows all the existing versions and the relationships between the versions. By history, CM Synergy means all of the file versions created before the current file version (called predecessors) and all of the file versions created after the current file version (called successors). This functionality allows for the tracking of all modifications to a file.

6.2.3. Release

The release is a label that indicates the version of the project, in this case the release of BADA files. BADA Releases are usually identified by a two digit number, e.g. 3.3 or 3.4. However, the name of release in CM Synergy can be made out of any combination of alphabetic and numerical characters.

Like in the case of the file version, no information on the current BADA release is given in the BADA files.

6.3. SYNONYM FILE FORMAT

6.3.1. SYNONYM.LST File

The SYNONYM.LST file is an ASCII file which lists all aircraft types which are supported by the BADA revision. An example of the SYNONYM.LST file is given below (partial listing).

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC SYNONYM.LST CCCCCCCCCCCCC/
CC                                                                   /
CC                  BADA SYNONYM FILE                                /
CC                                                                   /
CC                                                                   /
CC       File_name: SYNONYM.LST                                      /
CC                                                                   /
CC       Creation_date: Mar 26 2002                                  /
CC                                                                   /
CC       Modification_date: Mar 26 2002                             /
CC                                                                   /
CC                                                                   /
CC====== Aircraft List ==============================================/
CC                                                                   /
CC   A/C     NAME OR MODEL       FILE                SYNONYMS        /
CC   CODE                                                            /
CC                                                                   /
 - A306__  AIRBUS A300B4-600   A306__              A306
 - A30B__  AIRBUS A300B4-200   A30B__              A30B   IL76
 - A310__  AIRBUS A310         A310__              A310
 - A319__  AIRBUS A319         A319__              A319
 - A320__  AIRBUS A320         A320__              A320   C17
 - A321__  AIRBUS A321         A321__              A321
 - A333__  AIRBUS A330-300     A333__              A333   A332
 - A343__  AIRBUS A340-300     A343__              A343   A342   A345
                                                          A346
 - AT43__  ATR ATR 42-300      AT43__              AT43   CN35   CVLT
                                                   AT44
 - AT45__  ATR ATR 42-500      AT45__              AT45
 - AT72__  ATR ATR 72          AT72__              AT72   A748
 - ATP___  ADVANCED TURBOPROP  ATP___              ATP    G222
 - B461__  BAE 146-100/RJ      B461__              B461   B462   B463
                                                   YK42
 - B703__  BOEING 707-300      B703__              B703   B720   K35R
                                                   E3TF   E3CF   C135
                                                   VC10   IL62
 - B722__  BOEING 727-100      B722__              B722   B721   BER4
 - B732__  BOEING 737-228      B732__              B732   B731   A124
 - B733__  BOEING 737-300      B733__              B733
 - B734__  BOEING 737-400      B734__              B734
 - B735__  BOEING 737-500      B735__              B735   B736
 - B737__  BOEING 737-700      B737__              B737
```

There are three types of lines in the SYNONYM.LST file with the line type identified by the first two characters in the line. These line types with their associated leading characters are listed below.

CC comment line

CD data line

\- synonym line

The data is organised into two blocks separated by a comment line consisting of the block name and equal signs "=":

- file identification block
- aircraft list block

Each of these blocks is described in the subsections below.

6.3.1.1. File Identification Block

The file identification block provides information on the file name, creation and modification date. The block consists of 12 comment lines.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC SYNONYM.LST CCCCCCCCCCCCC/
CC                                                                   /
CC                  BADA SYNONYM FILE                                /
CC                                                                   /
CC                                                                   /
CC      File_name: SYNONYM.LST                                       /
CC                                                                   /
CC      Creation_date: Mar 26 2002                                   /
CC                                                                   /
CC      Modification_date: Mar 26 2002                              /
```

The comment lines specify the file name along with the creation and the modification date. The creation date indicates the date when the file was created for the first time. The modification date indicates when the contents of the file were last modified.

6.3.1.2. Aircraft Listing Block

The aircraft listing block consists of 5 comment lines with additional synonym lines for each aircraft supported by the BADA Revision. A partial listing of this block is shown below.

```
CC====== Aircraft List ===============================================/
CC                                                                   /
CC   A/C    NAME OR MODEL        FILE                SYNONYMS        /
CC   CODE                                                            /
CC                                                                   /
 - A306__  AIRBUS A300B4-600    A306__              A306
 - A30B__  AIRBUS A300B4-200    A30B__              A30B   IL76
 - A310__  AIRBUS A310          A310__              A310
 - A319__  AIRBUS A319          A319__              A319
 - A320__  AIRBUS A320          A320__              A320   C17
 - A321__  AIRBUS A321          A321__              A321
 - A333__  AIRBUS A330-300      A333__              A333   A332
 - A343__  AIRBUS A340-300      A343__              A343   A342
 - AT43__  ATR ATR 42-300       AT43__              AT43   CN35   CVLT
                                                    AT44
 - AT45__  ATR ATR 42-500       AT45__              AT45
 - AT72__  ATR ATR 72           AT72__              AT72   A748
 - ATP___  ADVANCED TURBOPROP   ATP___              ATP    G222
 - B461__  BAE 146-100/RJ       B461__              B461   B462   B463
                                                    YK42
 - B703__  BOEING 707-300       B703__              B703   B720   K35R
                                                    E3TF   E3CF   C135
                                                    VC10   IL62
 - B722__  BOEING 727-100       B722__              B722   B721   BER4
 - B732__  BOEING 737-228       B732__              B732   B731   A124
 - B733__  BOEING 737-300       B733__              B733
 - B734__  BOEING 737-400       B734__              B734
 - B735__  BOEING 737-500       B735__              B735   B736
 - B737__  BOEING 737-700       B737__              B737
```

There is one synonym line for each of the directly supported aircraft within the BADA release. Each such line consists of 4 fields as described below:

(a) Aircraft Code Field

This field identifies the aircraft type. It consists of a three or four-character ICAO code followed by two or more underscore characters.

(b) Name or Model Field

This field identifies the manufacturer and model of the aircraft.

(c) File Name Field

This field identifies the file name for the APF, OPF, PTF or PTD files associated with the aircraft (minus the file extension). For each aircraft this is the same as the A/C code.

(d) Equivalence Field

This field lists any equivalences associated with the aircraft. By default, each aircraft has at least one equivalence to itself.

Note that in some cases the name or model or equivalence fields may be continued onto the next line as it is the case with the B703 model.

6.3.2. SYNONYM.NEW File

The SYNONYM.NEW file is an ASCII file, which lists all aircraft types, which are supported by the BADA revision. Its format differs from the SYNONYM.LST file in that all supported aircraft are listed alphabetically in the file whether they are supported directly or by equivalence. An example of the SYNONYM.NEW file is given below (partial listing).

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC SYNONYM.NEW CCCCCCCCCCCCCC/
CC                                                                   /
CC                BADA SYNONYM FILE                                  /
CC                                                                   /
CC                                                                   /
CC      File_name: SYNONYM.NEW                                       /
CC                                                                   /
CC      Creation_date: Mar 26 2002                                   /
CC                                                                   /
CC      Modification_date: Mar 26 2002                              /
CC                                                                   /
CC                                                                   /
CC====== Aircraft List ==============================================/
CC                                                                   /
CC   A/C    MANUFACTURER        NAME OR MODEL            FILE    OLD  /
CC   CODE                                                        CODE /
CC                                                                   /
CD * A10    FAIRCHILD           THUNDERBOLT II           FGTN__  A10A /
CD * A124   ANTONOV             ANTONOV AN-124           B732__  AN4R /
CD - A306   AIRBUS              A300B4-600               A306__  A306 /
CD - A30B   AIRBUS              A300B4-200               A30B__  A300 /
CD - A310   AIRBUS              A310                     A310__  A310 /
CD - A319   AIRBUS              A319                     A319__  A319 /
CD - A320   AIRBUS              A320                     A320__  EA32 /
CD - A321   AIRBUS              A321                     A321__  A321 /
CD * A332   AIRBUS              A330-200                 A333__  A332 /
CD - A333   AIRBUS              A330-300                 A333__  A330 /
CD * A342   AIRBUS              A340-200                 A343__  A342 /
CD - A343   AIRBUS              A340-300                 A343__  A340 /
CD * A345   AIRBUS              A340-500                 A343__  A345 /
CD * A346   AIRBUS              A340-600                 A343__  A346 /
CD * A4     MCDONNELL-DOUGLAS   SKYHAWK                  FGTN__  A4   /
CD * A6     GRUMMAN             INTRUDER                 FGTN__  EA6B /
CD * A748   BAE                 BAE 748                  AT72__  HN74 /
CD * AC80   ROCKWELL            TURBO COMMANDER          BE20__  AC6T /
CD * AC90   ROCKWELL            TURBO COMMANDER          BE20__  AC90 /
CD * AC95   ROCKWELL            TURBO COMMANDER          BE20__  AC95 /
CD * AJET   DASSAULT            ALPHA JET                FGTN__  AJET /
CD * AMX    EMBRAER             AMX                      FGTN__  AMX  /
CD * AN12   ANTONOV             AN-12                    C130__  AN12 /
CD * AN24   ANTONOV             AN-124                   F27___  AN24 /
CD * AN26   ANTONOV             AN-26                    F27___  AN26 /
```

There are three types of lines in the SYNONYM.NEW file with the line type identified by the first two characters in the line. These line types with their associated two leading characters are listed below.

CC	comment line
CD	data line
FI	end-of-file line

The data is organised into two blocks separated by a comment line consisting of the block name and equal signs "=":

- file identification block
- aircraft list block

Each of these blocks is described in the subsections below.

6.3.2.1. File Identification Block

The file identification block provides information on the file name, creation and modification date. The block consists of 12 comment lines as shown below.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC SYNONYM.NEW CCCCCCCCCCCCCCC/
CC                                                                    /
CC                 BADA SYNONYM FILE                                  /
CC                                                                    /
CC                                                                    /
CC      File_name: SYNONYM.NEW                                        /
CC                                                                    /
CC      Creation_date: Mar 26 2002                                    /
CC                                                                    /
CC      Modification_date: Mar 26 2002                               /
CC                                                                    /
```

The comment lines specify the file name along with the creation and last modification date. The creation date indicates the date when the file was created for the first time. The modification date indicates when the contents of the file were last modified.

6.3.2.2. Aircraft Listing Block

The aircraft listing block consists of 5 comment lines and at least one data line for each aircraft supported by the BADA Revision. Some aircraft have more than one data line, see under (f). A partial listing of this block is shown below.

```
CD * A10    FAIRCHILD           THUNDERBOLT II           FGTN__   A10A /
CD * A124   ANTONOV             ANTONOV AN-124           B732__   AN4R /
CD - A306   AIRBUS              A300B4-600               A306__   A306 /
CD - A30B   AIRBUS              A300B4-200               A30B__   A300 /
```

Each data line consists of 6 fields as described below:

(a) Support Type Field

This field is one character in length being one of the following two values:

"-" to indicate an aircraft type directly supported, and,

"*" to indicate an aircraft type supported by equivalence with another directly supported aircraft

(b) Aircraft Code Field

This field identifies the aircraft type. It consists of a three or four-character ICAO code.

(c) Manufacturer Field

This field identifies the manufacturer of the aircraft. Examples are Boeing, Airbus or Fokker.

(d) Name or Model Field

This field identifies the name or model for the aircraft type. Examples are the 747-400 series or Learjet 35.

(e) File Field

This field indicates the name of the OPF, APF, PTF or PTD file, which contains the parameters for the aircraft type (minus the file extension).

For an aircraft type which is directly supported this file name will be the same as the ICAO code with an additional two or more underscore characters to form a string of six characters in length. For example, the file name corresponding to the A333 will be A333__. This indicates an OPF file A333__.OPF, an APF file A333__.APF, a PTF file A333__.PTF and a PTD file A333__.PTD. For the Fokker F-27 with an ICAO code of F27, the file names include three underscore characters, that is, F27___.OPF, F27___.APF, F27___.PTF and F27___.PTD.

For an aircraft type which is supported through equivalence the file name will indicate the file for the equivalent aircraft type which should be used. As an example, the Antonov 12 (AN12) is equivalent to the Lockheed C-130 Hercules (C130). Thus the files C130__.OPF, C130__.APF, C130__.PTF and C130__.PTD should be used.

(f) Old Code field

The old code field gives the name of the aircraft that refers to the formerly known aircraft designator as published in one of the previous editions of the ICAO document 8643 [RD10]. This allows the BADA 3.7 user to continue to use the old ICAO standard and to establish a link between the old and the new aircraft designators.

The above fields are specified in the following fixed format (Fortran notation):

'CD', 1X, A1, 1X, A4, 3X, A18, 1X, A25, 1X, A6, 2X, A4

6.3.3. SYNONYM_ALL.LST File

The SYNONYM_ALL.LST file is an ASCII file, which lists all aircraft types, which are supported by the BADA revision. Like in the SYNONYM.NEW file, all supported aircraft are listed alphabetically in the file whether they are supported directly or by equivalence. An example of the SYNONYM_ALL.LST file is given below (partial listing).

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC SYNONYM_ALL.LST CCCCCCCCCCCCCCC/
CC                                                                    /
CC                BADA SYNONYM_ALL FILE                               /
CC                                                                    /
CC                                                                    /
CC      File_name: SYNONYM_ALL.LST                                    /
CC                                                                    /
CC      Creation_date: May 22 2003                                    /
CC                                                                    /
CC      Modification_date: May 22 2003                                /
CC                                                                    /
CC                                                                    /
CC                                                                    /
CC====================================================================/
CC                                                                    /
CC                                                                    /
CC                                                          ICAO    ICAO    ICAO    ICAO    ICAO    ICAO   ICAO
CC   A/C    NAME OR MODEL    MANUFACTURER  FILE             CODE    CODE    CODE    CODE    CODE    CODE   CODE
CC                                        BADA 3.5           V24     V25     V26    V27     V28     V29    V30
CC
CD * A10    THUNDERBOLT II    FAIRCHILD    FGTN__           A10A    A10     A10     A10     A10     A10    A10
CD * A124   ANTONOV AN-124    ANTONOV      B732__           AN4R    A124    A124    A124    A124    A124   A124
CD - A306   A300B4-600        AIRBUS       A306__           A306    A306    A306    A306    A306    A306   A306
CD - A30B   A300B4-200        AIRBUS       A30B__           EA30    A300    A30B    A30B    A30B    A30B   A30B
CD - A310   A310              AIRBUS       A310__           EA31    A310    A310    A310    A310    A310   A310
CD * A318   A318              AIRBUS       A319__           A318    A318    A318    A318    A318    A318   A318
CD - A319   A319              AIRBUS       A319__           A319    A319    A319    A319    A319    A319   A319
CD - A320   A320              AIRBUS       A320__           EA32    A320    A320    A320    A320    A320   A320
CD - A321   A321              AIRBUS       A321__           A321    A321    A321    A321    A321    A321   A321
CD - A332   A330-200          AIRBUS       A332__           A332    A332    A332    A332    A332    A332   A332
CD - A333   A330-300          AIRBUS       A333__           EA33    EA33    EA33    A330    A333    A333   A333
CD * A342   A340-200          AIRBUS       A343__           A342    A342    A342    A342    A342    A342   A342
CD - A343   A340-300          AIRBUS       A343__           EA34    EA34    EA34    A340    A343    A343   A343
CD * A345   A340-500          AIRBUS       A343__           A345    A345    A345    A345    A345    A345   A345
CD * A346   A340-600          AIRBUS       A343__           A346    A346    A346    A346    A346    A346   A346
```

There are three types of lines in the SYNONYM_ALL.LST file with the line type identified by the first two characters in the line. These line types with their associated two leading characters are listed below.

CC comment line
CD data line
FI end-of-file line

The data is organised into two blocks separated by a comment line consisting of equal signs "=":

- file identification block
- aircraft list block

Each of these blocks is described in the subsections below.

6.3.3.1. File Identification Block

The file identification block provides information on the file name, creation and modification date. The block consists of 13 comment lines as shown below.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC SYNONYM_ALL.LST CCCCCCCCCCCCCCC/
CC                                                                    /
CC                  BADA SYNONYM_ALL FILE                             /
CC                                                                    /
CC                                                                    /
CC      File_name: SYNONYM.NEW                                        /
CC                                                                    /
CC      Creation_date: May 22 2003                                    /
CC                                                                    /
CC      Modification_date: May 22 2003                               /
CC                                                                    /
```

The comment lines specify the file name along with the creation and last modification date. The creation date indicates the date when the file was created for the first time. The modification date indicates when the contents of the file were last modified.

6.3.3.2. Aircraft Listing Block

The aircraft listing block consists of 7 comment lines and at least one data line for each aircraft supported by the BADA Revision. Some aircraft have more than one data line, see under (f). A partial listing of this block is shown below.

```
* A10    THUNDERBOLT II   FAIRCHILD    FGTN__     A10A     A10      A10      A10      A10      A10      A10
* A124   ANTONOV AN-124   ANTONOV      B732__     AN4R     A124     A124     A124     A124     A124     A124
- A306   A300B4-600       AIRBUS       A306__     A306     A306     A306     A306     A306     A306     A306
- A30B   A300B4-200       AIRBUS       A30B__     EA30     A300     A30B     A30B     A30B     A30B     A30B
```

Each data line consists of 5 fields describing the aircraft type and number of additional fields providing the history of ICAO aircraft type designators. Detailed description is given below:

(a) Support Type Field

This field is one character in length being one of the following two values:

"-" to indicate an aircraft type directly supported, and,

"*" to indicate an aircraft type supported by equivalence with another directly supported aircraft

(b) Aircraft Code Field

This field identifies the aircraft type. It consists of a three or four-character ICAO code.

(c) Manufacturer Field

This field identifies the manufacturer of the aircraft. Examples are Boeing, Airbus or Fokker.

(d) Name or Model Field

This field identifies the name or model for the aircraft type. Examples are the 747-400 series or Learjet 35.

(e) File Field

This field indicates the name of the OPF, APF, PTF or PTD file, which contains the parameters for the aircraft type (minus the file extension).

For an aircraft type which is directly supported this file name will be the same as the ICAO code with an additional two or more underscore characters to form a string of six characters in length. For example, the file name corresponding to the A333 will be A333__. This indicates an OPF file A333__.OPF, an APF file A333__.APF, a PTF file A333__.PTF and a PTD file A333__.PTD. For the Fokker F-27 with an ICAO code of F27, the file names include three underscore characters, that is, F27___.OPF, F27___.APF, F27___.PTF and F27___.PTD.

For an aircraft type which is supported through equivalence the file name will indicate the file for the equivalent aircraft type which should be used. As an example, the Antonov 12 (AN12) is equivalent to the Lockheed C-130 Hercules (C130). Thus the files C130__.OPF, C130__.APF, C130__.PTF and C130__.PTD should be used.

(f) Old Code fields

The old code fields give the name of the aircraft that refers to the formerly known aircraft designator as published in one of the previous editions (versions, i.e. V24 to V36) of the ICAO document 8643 [RD10]. This allows the BADA 3.7 user to continue to use the old ICAO standard and to establish a link between the old and the new aircraft designators, as well as the corresponding BADA aircraft file name.

6.4. OPF FILE FORMAT

The Operations Performance File (OPF) is an ASCII file, which for a particular aircraft type specifies the operations performance parameters described in Section 3. An example of an OPF file for the A306 (Airbus 300B4-600) aircraft is shown below.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC A306__.OPF CCCCCCCCCCCCCC/
CC                                                                    /
CC                  AIRCRAFT PERFORMANCE OPERATIONAL FILE             /
CC                                                                    /
CC                                                                    /
CC      File_name: A306__.OPF                                         /
CC                                                                    /
CC      Creation_date: Mar 26 2002                                    /
CC                                                                    /
CC      Modification_date: Mar 26 2002                               /
CC                                                                    /
CC                                                                    /
CC====== Actype ======================================================/
CD    A306__         2 engines     Jet                    H           /
CC    Airbus A300-B4-622 with PW4158  engines             wake        /
CC                                                                    /
CC====== Mass (t) ====================================================/
CC     reference      minimum      maximum     max payload  mass grad /
CD      .14000E+03   .87000E+02   .17170E+03   .39000E+02   .14100E+00 /
CC====== Flight envelope =============================================/
CC      VMO(KCAS)       MMO        Max.Alt        Hmax       temp grad /
CD      .33500E+03   .82000E+00   .41000E+05   .31600E+05  -.67000E+02 /
CC====== Aerodynamics ================================================/
CC Wing Area and Buffet coefficients (SIM)                            /
CCndrst Surf(m2)     Clbo(M=0)       k          CM16                  /
CD 5    .26000E+03   .15300E+01   .10290E+01   .00000E+00             /
CC    Configuration characteristics                                   /
CC n Phase  Name     Vstall(KCAS)    CD0         CD2         unused   /
CD 1 CR    Clean     .15100E+03   .19000E-01   .53000E-01   .00000E+00 /
CD 2 IC    S15F00    .11700E+03   .33057E-01   .45362E-01   .00000E+00 /
CD 3 TO    S15F00    .11700E+03   .33057E-01   .45362E-01   .00000E+00 /
CD 4 AP    S15F15    .10900E+03   .38031E-01   .44932E-01   .00000E+00 /
CD 5 LD    S30F40    .97000E+02   .78935E-01   .44822E-01   .00000E+00 /
CC    Spoiler                                                         /
CD 1       RET                                                        /
CD 2       EXT                                 .00000E+00   .00000E+00 /
CC    Gear                                                            /
CD 1       UP                                                         /
CD 2       DOWN                   .22500E-01   .00000E+00   .00000E+00 /
CC    Brakes                                                          /
CD 1       OFF                                                        /
CD 2       ON                                  .00000E+00   .00000E+00 /
CC====== Engine Thrust ===============================================/
CC          Max climb thrust coefficients (SIM)                       /
CD      .30400E+06   .44800E+05   .11600E-09   .67500E+01   .42600E-02 /
CC       Desc(low)    Desc(high)   Desc level   Desc(app)    Desc(ld)  /
CD      .73000E-02   .20600E-01   .80000E+04   .12000E+00   .36000E+00 /
CC       Desc CAS     Desc Mach    unused       unused       unused    /
CD      .28000E+03   .79000E+00   .00000E+00   .00000E+00   .00000E+00 /
CC====== Fuel Consumption ============================================/
CC    Thrust Specific Fuel Consumption Coefficients                   /
CD      .88100E+00   .16900E+05                                       /
CC    Descent Fuel Flow Coefficients                                  /
CD      .26805E+02   .45700E+05                                       /
CC    Cruise Corr.     unused       unused       unused       unused   /
CD      .10380E+01   .00000E+00   .00000E+00   .00000E+00   .00000E+00 /
CC====== Ground ======================================================/
CC         TOL          LDL         span         length       unused   /
CD      .23620E+04   .15550E+04   .44840E+02   .54080E+02   .00000E+00 /
CC====================================================================/
FI                                                                    /
```

There are three types of lines in the OPF file with the line type identified by the first two characters in the line. These line types with their associated two leading characters are listed below.

CC comment line

CD data line

FI end-of-file line

The comment lines are provided solely for the purpose of improving the readability of the file. All coefficients are contained within the CD lines in a fixed format. The end-of-file line is included as the last line in the file in order to facilitate the reading of the file in certain computing environments.

The data is organised into a total of eight blocks with each block separated by a comment line containing the block name and equal signs "=". These blocks are listed below and are described in further detail in the subsections below.

- file identification block
- aircraft type block
- mass block
- flight envelope block
- aerodynamics block
- engine thrust block,
- fuel consumption block
- ground movements block

6.4.1. File Identification Block

The file identification block provides information on the file name, creation date and modification date. The block consists of 11 comment lines. An example of the file identification block for the A306__.OPF file is shown below.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC A306__.OPF CCCCCCCCCCCCCCC/
CC                                                                     /
CC                  AIRCRAFT PERFORMANCE OPERATIONAL FILE              /
CC                                                                     /
CC                                                                     /
CC       File_name: A306__.OPF                                         /
CC                                                                     /
CC       Creation_date: Mar 26 2002                                    /
CC                                                                     /
CC       Modification_date: Mar 26 2002                                /
CC                                                                     /
```

The comment lines specify the file name along with the creation date and last modification date. The creation date indicates the date when the file was created for the first time. The modification date indicates when the contents of the file were last modified.

6.4.2. Aircraft Type Block

The OPF aircraft type block consists of 1 data line with 3 comment lines for a total of 4 lines. An example of the aircraft type block is given below.

```
       CC====== Actype ======================================================/
1 ->    CD    A306__          2 engines     Jet                     H         /
       CC    Airbus A300-B4-622 with PW4158   engines              wake        /
       CC                                                                    /
```

The data line specifies the following aircraft type parameters:

- ICAO aircraft code (followed by 2 or more underscore characters as required to form a six character string),
- number of engines, n_{eng} ,
- engine type, and,
- wake category

The engine type can be one of the following three values: Jet, Turboprop or Piston. The wake category can be one of the three values H (heavy), M (medium) or L (light).

The four values are specified in the following fixed format (Fortran notation)

'CD', 2X, A6, 10X, I1, 12X, A9, 17X , A1

The comment lines typically indicate the engine manufacturer's designation and the source of the performance coefficients.

6.4.3. Mass Block

The OPF mass block consists of 1 data line with 2 comment lines for a total of 3 lines.

An example of the mass block is given below.

```
        CC====== Mass (t) ==================================================/
        CC     reference      minimum      maximum     max payload  mass grad  /
1 ->    CD      .14000E+03   .87000E+02   .17170E+03   .39000E+02   .14100E+00 /
```

The data line specifies the following BADA mass model parameters:

m_{ref} m_{min} m_{max} m_{pyld} G_W

These parameters are specified in the following fixed format (Fortran notation)

'CD', 2X, 5(3X, E10.5)

6.4.4. Flight Envelope Block

The OPF flight envelope block consists of 1 data line with 2 comment lines for a total of 3 lines. An example of the flight envelope block is given below.

```
        CC====== Flight envelope ============================================/
        CC      VMO(KCAS)       MMO         Max.Alt       Hmax       temp grad  /
1 ->    CD      .33500E+03   .82000E+00   .41000E+05   .31600E+05  -.67000E+02 /
```

The date line specifies the following BADA speed envelope parameters:

V_{MO} M_{MO} h_{MO} h_{max} G_t

Note that all altitudes are expressed in feet.

These parameters are specified in the following fixed format (Fortran notation):

'CD' , 2X, 5 (3X, E10.5)

6.4.5. Aerodynamics Block

The OPF aerodynamics block consists of 12 data lines and 8 comment lines for a total of 20 lines. An example of the aerodynamics block is given below.

```
         CC====== Aerodynamics ================================================/
         CC Wing Area and Buffet coefficients (SIM)                            /
         CCndrst Surf(m2)     Clbo(M=0)      k            CM16                 /
 1 ->    CD 5   .26000E+03   .15300E+01   .10290E+01   .00000E+00              /
         CC   Configuration characteristics                                    /
         CC n Phase  Name    Vstall(KCAS)    CD0          CD2        unused    /
 2 ->    CD 1 CR   Clean     .15100E+03   .19000E-01   .53000E-01   .00000E+00 /
 3 ->    CD 2 IC   S15F00    .11700E+03   .33057E-01   .45362E-01   .00000E+00 /
 4 ->    CD 3 TO   S15F00    .11700E+03   .33057E-01   .45362E-01   .00000E+00 /
 5 ->    CD 4 AP   S15F15    .10900E+03   .38031E-01   .44932E-01   .00000E+00 /
 6 ->    CD 5 LD   S30F40    .97000E+02   .78935E-01   .44822E-01   .00000E+00 /
         CC   Spoiler                                                          /
 7 ->    CD 1      RET                                                         /
 8 ->    CD 2      EXT                                 .00000E+00   .00000E+00 /
         CC   Gear                                                             /
 9 ->    CD 1      UP                                                          /
 10 ->   CD 2      DOWN                    .2250E-01   .00000E+00   .00000E+00 /
         CC   Brakes                                                           /
 12 ->   CD 1      OFF                                                         /
 13 ->   CD 2      ON                                   .00000E+00   .00000E+00 /
```

The first data line specifies the following BADA aerodynamic model parameters:

S Clbo(M=0) k C_{M16}

These parameters are specified in the following fixed format (Fortran notation):

'CD', 2X, 4 (3X, E10.5)

Note that the "5" under the header "ndrst" stands for the five <u>dr</u>ag <u>s</u>e<u>t</u>tings. Currently this is not used but is left in for compatibility requirements.

The next line holds besides the stall speed and flap setting for cruise as well as the values for the two drag coefficients for this configuration:

$(V_{stall})_{CR}$ C_{D0} C_{D2}

These parameters are specified in the following fixed format (Fortran notation):

'CD', 15X, 3 (3X, E10.5)

The next four data lines have the same format and correspond to the other configurations. The configurations are specified in the following order, corresponding to a semi-monotonically decreasing stall speed:

IC initial climb

TO take-off

AP approach

LD landing

The stall speed, $(V_{stall})_i$, is specified for each configuration, and C_{D0} and C_{D2} are given if available in the following fixed format (Fortran notation):

'CD', 15X, 3 (3X, E10.5)

In case the IC configuration is equal to the CR configuration, the values for C_{D0} and C_{D2} are mentioned only in the CR dataline. Note that C_{D0} and C_{D2} coefficients for IC and TO configurations are not used but are included for the reason of compatibility with previous versions.

The data lines 7 through 9 are not used but are included for the reason of compatibility with previous versions.

Dataline 10 holds the drag increment for landing gear down:

$C_{D0\ \Delta LDG}$

The format of this line is:

'CD', 31X, E10.5

Datalines 11 and 12 are not used but are included for the reason of compatibility with previous versions.

6.4.6. Engine Thrust Block

The OPF engine thrust block consists of 3 data lines with 4 comment lines for a total of 7 lines. An example of the engine thrust block is given below.

```
        CC====== Engine Thrust =============================================/
        CC          Max climb thrust coefficients (SIM)                     /
1 ->    CD      .30400E+06   .44800E+05   .11600E-09   .67500E+01   .42600E-02 /
        CC       Desc(low)    Desc(high)   Desc level   Desc(app)    Desc(ld)  /
2 ->    CD      .73000E-02   .20600E-01   .80000E+04   .12000E+00   .36000E+00 /
        CC       Desc CAS     Desc Mach    unused       unused       unused    /
3 ->    CD      .28000E+03   .79000E+00   .00000E+00   .00000E+00   .00000E+00 /
```

The first data line specifies the following BADA parameters used to calculate the maximum climb thrust, that is:

$C_{Tc,1}$ $C_{Tc,2}$ $C_{Tc,3}$ $C_{Tc,4}$ $C_{Tc,5}$

These parameters are specified in the following fixed format (Fortran notation):

'CD', 2X, 5 (3X, E10.5)

The second data line specifies the following BADA parameters used to calculate cruise and descent thrust, that is:

$C_{Tdes,low}$ $C_{Tdes,high}$ h_{des} $C_{Tdes,app}$ $C_{Tdes,ld}$

These parameters are specified in the following fixed format (Fortran notation):

'CD', 2X, 5 (3X, E10.5)

Note that the $C_{Tdes,app}$ and $C_{Tdes,ld}$ coefficients are determined in order to obtain a 3° descent gradient during approach and landing.

The third data line specifies the reference speeds during descent, that is:

$V_{des,ref}$ $M_{des,ref}$

These parameters are specified in the following fixed format (Fortran notation):

'CD', 2X, 2 (3X, E10.5)

Note that these two parameters are no longer used in BADA model implementation, but are left in place only to provide information on one of the reference speeds during descent used during the model identification.

The zero values at the end of this data line are not used but are included in the file due to compatibility requirements with previous versions.

6.4.7. Fuel Consumption Block

The OPF fuel consumption block consists of 3 data lines with 4 comment lines for a total of 7 lines. An example of a fuel consumption block is shown below.

```
        CC====== Fuel Consumption ============================================/
        CC    Thrust Specific Fuel Consumption Coefficients                    /
1 ->    CD      .88100E+00    .16900E+05                                       /
        CC    Descent Fuel Flow Coefficients                                   /
2 ->    CD      .26805E+02    .45700E+05                                       /
        CC    Cruise Corr.     unused        unused        unused        unused   /
3 ->    CD      .10380E+01    .00000E+00    .00000E+00    .00000E+00    .00000E+00 /
```

The first data line specifies the following BADA parameters for thrust specific fuel consumption.

C_{f1} C_{f2}

These parameters are specified in the following fixed format (Fortran notation):

'CD', 2X, 2 (3X , E10.5)

The second data line specifies the following BADA parameters for descent fuel flow.

C_{f3} C_{f4}

These parameters are specified in the following fixed format (Fortran notation):

'CD', 2X, 2 (3X, E10.5)

The third data line specifies the cruise fuel flow correction factor.

C_{fcr}

The parameter is specified in the following fixed format (Fortran notation):

'CD', 5X, E10.5

6.4.8. Ground Movement Block

The OPF ground movement block consists of 1 data line with 3 comment lines for a total of 4 lines. An example of a ground movement block is shown below. The ground movement block is the last block in the OPF file and is thus followed by the end-of-file line as shown below.

```
        CC====== Ground ==============================================================/
        CC         TOL           LDL          span          length        unused     /
1 ->    CD     .23620E+04   .15550E+04   .44840E+02   .54080E+02   .00000E+00 /
        CC==============================================================================/
        FI                                                                           /
```

The data line specifies the following BADA parameters for ground movements:

TOL LDL span length

These parameters are specified in the following fixed format (Fortran notation):

'CD', 2X, 4 (3X, E10.5)

6.5. APF FILE FORMAT

The Airlines Procedures File (APF) is an ASCII file which, for a particular aircraft type, specifies recommended speed procedures for climb, cruise, and descent conditions. An example of an APF file for the Airbus A306 aircraft is shown below.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC A306__.APF CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC/
CC                                                                                                 /
CC                 AIRLINES PROCEDURES FILE                                                        /
CC                                                                                                 /
CC      File_name: A306__.APF                                                                      /
CC                                                                                                 /
CC      Creation_date: Mar 26 2002                                                                 /
CC                                                                                                 /
CC      Modification_date: Mar 26 2002                                                             /
CC                                                                                                 /
CC                                                                                                 /
CC                                                                                                 /
CC   LO= 087.00 to ---.--   /  AV= ---.-- to ---.--   /  HI= ---.-- to 171.70                      /
CC                                                                                                 /
CC=================================================================================================/
CC  COM CO    Company name ------climb-------  --cruise--  -----descent------  --approach-  model- /
CC                     mass  lo  hi               lo  hi         hi  lo          (unused)          /
CC    version engines  ma  cas cas mc xxxx xx  cas cas mc  mc cas cas xxxx xx  xxx xxx xxx  opf___ /
CC===:=======:=======::==::===:===:==:====:==::===:===:==::==:===:===:====:==::===:===:===::======:/
CD  *** **    Default Company                                                                      /
CD    B4_622  PW4158   LO  250 300 79          250 310 79  79 280 250            0   0   0  A306__ /
CD    B4_622  PW4158   AV  250 300 79          250 310 79  79 280 250            0   0   0  A306__ /
CD    B4_622  PW4158C  HI  250 300 79          250 310 79  79 280 250            0   0   0  A306__ /
CC===:=======:=======::==::===:===:==:====:==::===:===:==::==:===:===:====:==::===:===:===::======:/
CC/////////////////////////////////  THE END   ////////////////////////////////////////////////////
```

There are two types of lines in the APF file with the line type identified by the first two characters in the line. These line types with their associated two leading characters are listed below.

CC - comment line
CD - data line

The last line in the file, as shown above, is also a comment line.

The comment lines are provided solely for the purpose of improving the readability of the file. All coefficients are contained within the CD lines in a fixed format.

The data is organised into 2 blocks separated by a comment line containing a string of equal signs, "=":

- file identification block
- speed procedures block

Each of the two blocks is described further in the subsections below.

6.5.1. File Identification Block

The file identification block provides information on the file name, creation date and modification date. The block consists of 14 comment lines. An example of a file identification block is shown below.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC A306__.APF CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC/
CC                                                                                                   /
CC                 AIRLINES PROCEDURES FILE                                                          /
CC                                                                                                   /
CC      File_name: A306__.APF                                                                        /
CC                                                                                                   /
CC      Creation_date: Mar 26 2002                                                                   /
CC                                                                                                   /
CC      Modification_date: Mar 26 2002                                                               /
CC                                                                                                   /
CC                                                                                                   /
CC                                                                                                   /
CC   LO= 087.00 to ---.--  /  AV= ---.-- to ---.--  /  HI= ---.-- to 171.70                          /
CC                                                                                                   /
```

The comment lines provide background information on the file contents. In addition, the comment lines specify the file name along with the creation and last modification date. The creation date indicates the date when the file was created for the first time. The modification date indicates when the contents of the file were last modified.

The second last comment line in the identification block specifies three mass ranges for the aircraft in tonnes. That is, a low range (LO), average range (AV) and high range (HI). The definition of these ranges is used for interpreting the information presented below in the procedures specification block. In the example given above, all three ranges are assumed equivalent.

6.5.2. Procedures Specification Block

The APF procedures specification block consists of 4 data lines with 7 comment lines for a total of 11 lines. An example of a procedures specification block is shown below.

```
       CC==================================================================================================/
       CC  COM CO    Company name ------climb-------  --cruise--  -----descent------  --approach-  model- /
       CC                    mass  lo  hi              lo  hi          hi  lo          (unused)         /
       CC    version engines  ma  cas cas mc xxxx xx  cas cas mc  mc cas cas xxxx xx  xxx xxx xxx  opf___ /
       CC===:=======:=======::==::===:===:==:====:==::===:===:==::==:===:===:====:==::===:===:===::======:/
1 ->   CD  *** **    Default Company                                                                    /
2 ->   CD    B4_622  PW4158   LO  250 300 79           250 310 79  79 280 250             0   0   0  A306__ /
3 ->   CD    B4_622  PW4158   AV  250 300 79           250 310 79  79 280 250             0   0   0  A306__ /
4 ->   CD    B4_622  PW4158C  HI  250 300 79           250 310 79  79 280 250             0   0   0  A306__ /
       CC===:=======:=======::==::===:===:==:====:==::===:===:==::==:===:===:====:==::===:===:===::======:/
       CC/////////////////////////////////  THE END   ///////////////////////////////////////////////////
```

The first data line specifies the company name for which the next three datalines are valid. The company can be identified by its 3 and 2 letter code plus the company name. The dataline fomat is:

'CD', 2X, A3, 1X, A2, 4X, A15

As it is, within BADA all APF files specify procedures for only one "default" company.

The next three data lines specify the following parameters corresponding to climb, cruise and descent:

$V_{cl,1}$ $V_{cl,2}$ M_{cl} $V_{cr,1}$ $V_{cr,2}$ M_{cr} M_{des} $V_{des,2}$ $V_{des,1}$

Note that all Mach number values are also multiplied by a value of 100. For example, the 78 indicated for M_{cl} above corresponds to a Mach number of 0.78.

The three lines specify parameters for mass ranges of Low (LO), Average (AV) and High (HI) respectively. These parameters are specified in the following fixed format (Fortran notation):

'CD', 25X, 2(I3, 1X), I2, 10X, 2(I3, 1X), I2, 2X, I2, 2(1X, I3)

Note that approach values are set to zero. These values are not used but are included in the file due to compatibility requirements with previous versions.

Also, each line specifies an aircraft version number, engine, and operational model. The operational model is always the same as the file name. The version number may provide some additional information on the aircraft version covered by the file while the engine states which engine is used by the aircraft.

The file format is designed such that the four data lines can be repeated for the different companies which operate the aircraft and which may have different standard procedures. If data were to be provided for more than one company then the version, engine and operational model fields may be useful since different companies could operate different versions of the aircraft with different engines and thus different associated operational models.

6.6. PTF FILE FORMAT

The Performance Table File (PTF) is an ASCII file, which for a particular aircraft type specifies cruise, climb and descent performance at different flight levels. An example of a PTF file for the Airbus A306 aircraft is shown below.

```
                              BADA PERFORMANCE FILE         Apr 23 2002

AC/Type: A306
                              Source OPF File:              Mar 26 2002
                              Source APF file:              Mar 26 2002

 Speeds:   CAS(LO/HI)  Mach   Mass Levels [kg]        Temperature:   ISA
 climb   - 250/300     0.79   low      - 104400
 cruise  - 250/310     0.79   nominal  - 140000        Max Alt. [ft]:  41000
 descent - 250/280     0.79   high     - 171700
==========================================================================================
 FL |          CRUISE           |           CLIMB                 |       DESCENT
    |  TAS          fuel        |  TAS          ROCD         fuel   |  TAS  ROCD   fuel
    | [kts]        [kg/min]     | [kts]         [fpm]       [kg/min] | [kts] [fpm] [kg/min]
    |          lo    nom     hi |            lo  nom   hi    nom    |        nom    nom
==========================================================================================
  0 |                           |  157    2210 1990 1620   270.3  |  131   760    97.2
    |                           |                                 |
  5 |                           |  158    2190 1970 1600   267.3  |  132   780    96.1
    |                           |                                 |
 10 |                           |  159    2170 1950 1570   264.3  |  138   800    95.0
    |                           |                                 |
 15 |                           |  166    2290 2030 1650   261.5  |  149   850    94.0
    |                           |                                 |
 20 |                           |  167    2270 2010 1620   258.5  |  181  1020    31.0
    |                           |                                 |
 30 |  230     61.2  81.4 104.3 |  190    2750 2360 1920   253.0  |  230  1360    25.0
    |                           |                                 |
 40 |  233     61.2  81.4 104.4 |  225    3350 2780 2270   247.7  |  233  1380    24.5
    |                           |                                 |
 60 |  272     65.9  81.7  99.6 |  272    4210 3070 2370   236.8  |  240  1410    23.3
    |                           |                                 |
 80 |  280     65.8  81.7  99.7 |  280    4040 2930 2230   225.7  |  280  1550    22.1
    |                           |                                 |
100 |  289     65.8  81.7  99.8 |  289    3860 2780 2090   214.8  |  289  1590    20.9
    |                           |                                 |
120 |  297     65.7  81.7  99.8 |  356    3820 2800 2170   204.8  |  332  1880    19.8
    |                           |                                 |
140 |  306     65.6  81.7  99.9 |  366    3590 2610 2000   194.3  |  342  1920    18.6
    |                           |                                 |
160 |  389     82.4  93.1 105.3 |  377    3360 2410 1820   184.1  |  353  1960    17.4
    |                           |                                 |
180 |  401     82.1  92.9 105.1 |  388    3120 2220 1650   174.2  |  363  2000    16.2
    |                           |                                 |
200 |  413     81.7  92.6 104.9 |  400    2880 2020 1470   164.5  |  375  2040    15.1
    |                           |                                 |
220 |  425     81.3  92.3 104.7 |  412    2630 1810 1290   155.0  |  386  2080    13.9
    |                           |                                 |
240 |  438     80.9  91.9 104.5 |  425    2380 1610 1100   145.8  |  398  2120    12.7
    |                           |                                 |
260 |  452     80.4  91.6 104.3 |  438    2130 1400  920   136.9  |  411  2160    11.6
    |                           |                                 |
280 |  466     79.9  91.2 104.1 |  452    1880 1200  730   128.1  |  424  2200    10.4
    |                           |                                 |
290 |  468     78.4  90.1 103.4 |  459    1760 1090  640   123.9  |  431  2220     9.8
    |                           |                                 |
310 |  464     74.3  87.0 101.5 |  464    2200 1290  660   115.4  |  444  2250     8.6
    |                           |                                 |
330 |  459     70.6  84.7 100.6 |  459    1950 1050  420   107.2  |  459  2290     7.4
    |                           |                                 |
350 |  455     67.6  83.0  97.9 |  455    1700  810  170    99.2  |  455  3150     6.3
    |                           |                                 |
370 |  453     65.1  82.0  90.3 |  453    1320  510    0    91.6  |  453  2850     5.1
    |                           |                                 |
390 |  453     63.2  81.9  83.0 |  453    1080  260    0    84.1  |  453  2850     3.9
    |                           |                                 |
410 |  453     61.9  75.9  75.9 |  453     830   10    0    77.0  |  453  2880     2.8
========================================================================================
```

The OPF and APF files are generated as a result of a modelling process using MatLab [RD6]. Once these two files are generated, the PTF can be automatically generated. A brief summary of the format of these files is given below.

The header of each PTF file contains information as described below.

file creation date: This is in the first line, at the top-right corner

aircraft type: This is in the third line.

source file dates: The last modification dates of the OPF and APF files which were used to create the PTF file are given in the 4th and 5th lines respectively.

speeds: The speed laws for climb, cruise and descent are specified in lines 8, 9 and 10, that is:

climb	$V_{cl,1}$ / $V_{cl,2}$	M_{cl}
cruise	$V_{cr,1}$ / $V_{cr,2}$	M_{cr}
descent	$V_{des,1}$ / $V_{des,2}$	M_{des}

mass Levels: The performance tables provide data for three different mass levels in lines 8, 9 and 10 that is:

low	1.2 $m_{min.}$
nominal	m_{ref}
high	m_{max}

Note that the low mass is not the Minimum Mass but 1.2 times the minimum mass.

Temperature data: The temperature is mentioned in line 7. All PTF files currently only provide for ISA conditions.

Maximum altitude: The maximum altitude as specified in the OPF file, h_{MO} , is given in line 9.

The table of performance data within the file consists of 13 columns. Each of these columns is described below:

Column 1	FL
Column 2	cruise TAS (nominal mass) in knots
Column 3	cruise fuel consumption (low mass) in kg/min
Column 4	cruise fuel consumption (nominal mass) in kg/min
Column 5	cruise fuel consumption (high mass) in kg/min
Column 6	climb TAS (nominal mass) in knots
Column 7	rate of climb with reduced power (low mass) in fpm
Column 8	rate of climb with reduced power (nominal mass) in fpm
Column 9	rate of climb with reduced power (high mass) in fpm
Column 10	climb fuel consumption (nominal mass) in kg/min
Column 11	descent TAS (nominal mass) in knots
Column 12	rate of descent (nominal mass) in fpm
Column 13	descent fuel consumption (nominal mass) in kg/min

The format for data presented in each line of the table is as follows (Fortran notation).

I3, 4X, I3, 2X, 3(1X, F5.1), 5X, I3, 2X, 3(1X, I5), 3X, F5.1, 5X, I3, 2X, I5, 3X, F4.1

Further explanatory notes on the data presented in the performance tables are given below:

(a) Cruise data is only specified for flight levels greater than or equal to 30.

(b) Performance data is specified up to a maximum flight level of 510 or to highest level for which a positive rate of climb can be achieved at the low mass.

(c) True Air Speed for climb, cruise and descent is determined based on the speed schedules specified in Sections 4.1, 4.2 and 4.3 respectively.

(d) Rates of climb are calculated at each flight level assuming the energy share factors associated with constant CAS or constant Mach speed laws and using the reduced power correction as given in Section 3.8.

(e) The fuel consumption in climb is independent of the aircraft mass and thus only one value is given. There are three different climb rates however corresponding to low, nominal and high mass conditions.

(f) The rate of descent and fuel consumption in descent is calculated assuming the nominal mass. Values for other mass conditions are not given.

(g) Discontinuities in climb rate can occur for the following reasons:

- change in speed between flight levels (e.g. removal of 250 knot restriction above FL100),
- transition from constant CAS to constant Mach (typically around FL300),
- transition through the tropopause (FL360 for ISA),
- end of the application scope for reduced climb power (at 80% of h_{max}).

(h) Discontinuities in descent rate can occur for the following reasons:

- transition through tropopause (FL360 for ISA),
- transition from constant Mach to constant CAS,
- change in assumed descent thrust (specified by the BADA h_{des} parameter),
- change to approach or landing aerodynamic configuration,
- change in speed between flight levels (e.g. application of 250 knot limit below FL100).

(i) The PTF files are made with "non-clean" configuration data for approach and landing when such data is available (see Section 3.6.1).

(j) The performance data presented in the table are computed by using ‘point type’ calculation, that is without performing integration over time: aircraft weight is constant and does not account for consumed fuel, and speed changes take place immediately.

Note that all PTF files are available in document form in [RD9].

6.7. PTD FILE FORMAT

In addition to the data provided in the PTF file, more detailed climb and descent performance data are presented in the PTD file. An example of a PTD file for the Airbus A306 aircraft is shown below (partial listing):

```
BADA PERFORMANCE DATA                                         Feb 16 2009

AC/Type: A306
                              Source OPF File:                Sep 05 2008
                              Source APF file:                Sep 05 2008

 Speeds:   CAS(LO/HI)  Mach   Mass Levels [kg]        Temperature:  ISA
 climb   - 250/300     0.79   low     -  104400
 cruise  - 250/310     0.79   nominal -  140000       Max Alt. [ft]:  41000
 descent - 250/280     0.79   high    -  171700

Low mass CLIMBS
===============

 FL[-] T[K] p[Pa] rho[kg/m3] a[m/s] TAS[kt] CAS[kt]  M[-] mass[kg] Thrust[N] Drag[N] Fuel[kgm] ESF[-] ROC[fpm] TDC[N]  PWC[-]
     0 288 101325   1.225     340    136.35   136.35  0.21 104400    297160    85670   215.8    0.98    2452   186284   0.88
     5 287  99508   1.207     340    137.34   136.35  0.21 104400    294268    85680   213.9    0.98    2435   183727   0.88
    10 286  97717   1.190     339    138.34   136.35  0.21 104400    291385    85691   212.0    0.98    2417   181179   0.88
    15 285  95952   1.172     339    144.45   141.35  0.22 104400    288510    82072   211.0    0.97    2527   181833   0.88
    20 284  94213   1.155     338    145.51   141.35  0.22 104400    285643    82082   209.1    0.97    2509   179299   0.88
    30 282  90812   1.121     337    168.52   161.35  0.26 104400    279935    72295   209.0    0.96    2937   182892   0.88
    40 280  87511   1.088     336    202.72   191.35  0.31 104400    274260    67093   210.7    0.95    3470   182476   0.88
    60 276  81200   1.024     333    272.30   250.00  0.42 104400    263011    74643   213.7    0.91    4075   165917   0.88
    80 272  75262   0.963     331    280.34   250.00  0.44 104400    251895    74535   206.0    0.91    3925   156222   0.88
   100 268  69682   0.905     328    345.37   300.00  0.54 104400    240914    91120   207.0    0.87    3905   131941   0.88
   120 264  64441   0.849     326    355.51   300.00  0.56 104400    230066    90785   199.1    0.86    3703   122681   0.88
   140 260  59524   0.796     324    366.04   300.00  0.58 104400    219352    90425   191.3    0.85    3495   113561   0.88
   160 256  54915   0.746     321    376.97   300.00  0.60 104400    208772    90038   183.6    0.84    3281   104583   0.88
   180 252  50600   0.698     319    388.32   300.00  0.63 104400    198326    89622   175.8    0.83    3060    95748   0.88
   200 249  46563   0.653     316    400.10   300.00  0.65 104400    188013    89175   168.1    0.82    2834    87059   0.88
   220 245  42791   0.610     314    412.32   300.00  0.68 104400    177835    88694   160.4    0.81    2601    78516   0.88
   240 241  39271   0.569     311    425.00   300.00  0.70 104400    167790    88179   152.7    0.80    2364    70123   0.88
   260 237  35989   0.530     308    438.16   300.00  0.73 104400    157879    87627   145.0    0.79    2122    61879   0.88
   280 233  32932   0.493     306    451.80   300.00  0.76 104400    148102    87036   137.3    0.78    1875    53788   0.88
   290 231  31485   0.475     304    458.81   300.00  0.78 104400    143263    86725   133.4    0.78    1749    49800   0.88
   310 227  28745   0.442     302    463.54   293.28  0.79 104400    133687    83916   124.9    1.09    2184    43839   0.88
   330 223  26201   0.410     299    459.48   280.58  0.79 104400    124245    79587   115.8    1.09    2205    44658   1.00
   350 219  23842   0.380     297    455.37   268.17  0.79 104400    114936    75881   106.8    1.09    1911    39055   1.00
   370 217  21663   0.348     295    453.12   256.08  0.79 104400    105761    72808    98.1    1.00    1470    32953   1.00
   390 217  19677   0.316     295    453.12   244.46  0.79 104400     96720    70398    89.7    1.00    1174    26322   1.00
   410 217  17874   0.287     295    453.12   233.34  0.79 104400     87813    68640    81.5    1.00     855    19173   1.00
```

The performance values presented in the PTF file. They are generated in the same conditions as the corresponding PTF file: same aircraft, same source OPF and APF files, same speed laws, same mass levels, same temperature and same flight levels. The purpose of this file is mainly to provide the user with a greater number of computed parameters, especially intermediate parameters used to compute the final TAS and ROCD, which may be useful to validate an implementation of the BADA model.

The files consists of a header, conforming to the same format as the PTF file header described in Section 6.6, followed by performance data consisting of 4 sections:

- low mass climb performance
- nominal mass climb performance
- high mass climb performance
- nominal mass descent performance

Each section contains a table that presents, for several flight levels, a set of performance parameters spread across 16 columns. Each of these columns is described below:

Column 1	Flight level [FL]
Column 2	Temperature [K]
Column 3	Pressure [Pa]
Column 4	Air density [kg/m^3]
Column 5	Speed of sound [m/s]
Column 6	TAS [kt]
Column 7	CAS [kt]
Column 8	Mach [dimensionless]
Column 9	Mass [kg]
Column 10	Thrust [N]
Column 11	Drag [N]
Column 12	Fuel flow [kg/min]
Column 13	Energy share factor [dimensionless]
Column 14	Rate of climb/descent [ft/min]
Column 15	(T – D) * $C_{pow,red}$ [kg/min] (see section 3.8)
Column 16	- climb tables: Power reduction coefficient $C_{pow,red}$ [dimensionless] - descent table: Descent gradient [degree]

The format for data presented in each line of the table is as follows (Fortran notation):

Climb tables:

I6, 1X, I3, 1X, I6, 1X, F7.3, 1X, I7, 2(1X, F8.2), 1X, F7.2, 1X, I6, 2(1X, I9), 1X, F7.1, 1X, F7.2, 1X, I7, 1X, I8, 1X, F7.2

Descent tables:

I6, 1X, I3, 1X, I6, 1X, F7.3, 1X, I7, 2(1X, F8.2), 1X, F7.2, 1X, I6, 2(1X, I9), 1X, F7.1, 1X, F7.2, 1X, I7, 1X, I8, 1X, F8.2

6.8. BADA.GPF FILE FORMAT

The BADA.GPF file is an ASCII file which specifies the values of the global aircraft parameters (see Section 5). The complete BADA.GPF file is shown below:

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC BADA.GPF CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC/
CC                                                                                  /
CC                  GLOBAL PARAMETERS FILE                                          /
CC                                                                                  /
CC       File_name: BADA.GPF                                                        /
CC                                                                                  /
CC       Creation_date: Mar 26 2002                                                 /
CC                                                                                  /
CC       Modification_date: Mar 26 2002                                             /
CC                                                                                  /
CC                                                                                  /
CC======== Class ===================================================================/
CC                                                                                  /
CC Flight = civ,mil                                                                 /
CC Engine = jet,turbo,piston                                                        /
CC Phase  = to,ic,cl,cr,des,hold,app,lnd,gnd                                        /
CC                                                                                  /
CC======== Parameters List =========================================================/
CC                                                                                  /
CC Name              Unit                                                           /
CC Parameter        Flight  Engine           Phase                         Value    /
CC                                                                                  /
CC max. long. acc.   [fps2]                                                         /
CD acc_long_max     civ     jet,turbo,piston to,ic,cl,cr,des,hold,app,lnd  .20000E+01 /
CC max. norm. acc.   [fps2]                                                         /
CD acc_norm_max     civ     jet,turbo,piston to,ic,cl,cr,des,hold,app,lnd  .50000E+01 /
CC nom. bank angle   [deg]                                                          /
CD ang_bank_nom     civ     jet,turbo,piston to,lnd                        .15000E+02 /
CC nom. bank angle   [deg]                                                          /
CD ang_bank_nom     civ     jet,turbo,piston ic,cl,cr,des,hold,app         .35000E+02 /
CC nom. bank angle   [deg]                                                          /
CD ang_bank_nom     mil     jet,turbo,piston to,ic,cl,cr,des,hold,app,lnd  .50000E+02 /
CC max. bank angle   [deg]                                                          /
CD ang_bank_max     civ     jet,turbo,piston to,lnd                        .25000E+02 /
CC max. bank angle   [deg]                                                          /
CD ang_bank_max     civ     jet,turbo,piston hold                          .35000E+02 /
CC max. bank angle   [deg]                                                          /
CD ang_bank_max     civ     jet,turbo,piston ic,cl,cr,des,app              .45000E+02 /
CC max. bank angle   [deg]                                                          /
CD ang_bank_max     mil     jet,turbo,piston to,ic,cl,cr,des,hold,app,lnd  .70000E+02 /
CC exp. desc. fact. [-]                                                             /
CD C_des_exp        civ,mil jet,turbo,piston des                           .16000E+01 /
CC to thrust factor [-]                                                             /
CD C_th_to          mil,civ jet,turbo,piston to                            .12000E+01 /
CC cr thrust factor [-]                                                             /
CD C_th_cr          mil,civ jet,turbo,piston cr                            .95000E+00 /
CC max alt for to   [ft]                                                            /
CD H_max_to         mil,civ jet,turbo,piston to                            .40000E+03 /
CC max alt for ic   [ft]                                                            /
CD H_max_ic         mil,civ jet,turbo,piston ic                            .20000E+04 /
CC max alt for app   [ft]                                                           /
CD H_max_app        mil,civ jet,turbo,piston app                           .80000E+04 /
CC max alt for ld   [ft]                                                            /
CD H_max_ld         mil,civ jet,turbo,piston lnd                           .30000E+04 /
CC min speed coef.   [-]                                                            /
CD C_v_min          mil,civ jet,turbo,piston cr,ic,cl,des,hold,app,lnd     .13000E+01 /
CC min speed coef.   [-]                                                            /
CD C_v_min_to       mil,civ jet,turbo,piston to                            .12000E+01 /
CC spd incr FL < 15 [KCAS]                                                          /
CD V_cl_1           mil,civ jet              cl                            .50000E+01 /
CC spd incr FL < 30 [KCAS]                                                          /
CD V_cl_2           mil,civ jet              cl                            .10000E+02 /
CC spd incr FL < 40 [KCAS]                                                          /
CD V_cl_3           mil,civ jet              cl                            .30000E+02 /
CC spd incr FL < 50 [KCAS]                                                          /
CD V_cl_4           mil,civ jet              cl                            .60000E+02 /
CC spd incr FL < 60 [KCAS]                                                          /
CD V_cl_5           mil,civ jet              cl                            .80000E+02 /
```

```
CC spd incr FL < 5  [KCAS]                                                     /
CD V_cl_6          mil,civ turbo,piston     cl                        .20000E+02 /
CC spd incr FL < 10 [KCAS]                                                     /
CD V_cl_7          mil,civ turbo,piston     cl                        .30000E+02 /
CC spd incr FL < 15 [KCAS]                                                     /
CD V_cl_8          mil,civ turbo,piston     cl                        .35000E+02 /
CC spd incr FL < 10 [KCAS]                                                     /
CD V_des_1         mil,civ jet,turbo        des                       .50000E+01 /
CC spd incr FL < 15 [KCAS]                                                     /
CD V_des_2         mil,civ jet,turbo        des                       .10000E+02 /
CC spd incr FL < 20 [KCAS]                                                     /
CD V_des_3         mil,civ jet,turbo        des                       .20000E+02 /
CC spd incr FL < 30 [KCAS]                                                     /
CD V_des_4         mil,civ jet,turbo        des                       .50000E+02 /
CC spd incr FL < 5  [KCAS]                                                     /
CD V_des_5         mil,civ piston           des                       .50000E+01 /
CC spd incr FL < 10 [KCAS]                                                     /
CD V_des_6         mil,civ piston           des                       .10000E+02 /
CC spd incr FL < 15 [KCAS]                                                     /
CD V_des_7         mil,civ piston           des                       .20000E+02 /
CC hold. spd FL < 140 [KCAS]                                                   /
CD V_hold_1        mil,civ jet,turbo,piston hold                      .23000E+03 /
CC hold. spd FL < 200 [KCAS]                                                   /
CD V_hold_2        mil,civ jet,turbo,piston hold                      .24000E+03 /
CC hold. spd FL < 340 [KCAS]                                                   /
CD V_hold_3        mil,civ jet,turbo,piston hold                      .26500E+03 /
CC hold. spd FL > 340 [M]                                                      /
CD V_hold_4        mil,civ jet,turbo,piston hold                      .83000E+00 /
CC backtrack spd    [KCAS]                                                     /
CD V_backtrack     mil,civ jet,turbo,piston gnd                       .35000E+02 /
CC taxi spd         [KCAS]                                                     /
CD V_taxi          mil,civ jet,turbo,piston gnd                       .15000E+02 /
CC apron spd        [KCAS]                                                     /
CD V_apron         mil,civ jet,turbo,piston gnd                       .10000E+02 /
CC gate spd         [KCAS]                                                     /
 CD V_gate         mil,civ jet,turbo,piston gnd                       .50000E+01 /
CC Piston pow. red. [-]                                                        /
CD C_red_piston    mil,civ piston           ic,cl                     .000000+00 /
CC Turbo pow. red.  [-]                                                        /
CD C_red_turbo     mil,civ turbo            ic,cl                     .250000+00 /
CC Jet power red.   [-]                                                        /
CD C_red_jet       mil,civ jet              ic,cl                     .150000+00 /
FI=============================================================================/
CC//////////////////////////////  THE END  ////////////////////////////////////////////
```

There are three types of lines in the BADA.GPF file with the line type identified by the first two characters in the line. These line types with their associated two leading characters are listed below.

CC	comment line
CD	data line
FI	end-of-file line

The data is organised into three blocks separated by a comment line consisting of the block name and equal signs "=":

- file identification block
- class block
- parameter block

Each of these blocks is described in the subsections below.

6.8.1. File Identification Block

The file identification block provides information on the file name, creation and modification date. The block consists of 12 comment lines.

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC BADA.GPF CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC/
CC                                                                                   /
CC                 GLOBAL PARAMETERS FILE                                            /
CC                                                                                   /
CC      File_name: BADA.GPF                                                          /
CC                                                                                   /
CC      Creation_date: Mar 26 2002                                                   /
CC                                                                                   /
CC      Modification_date: Mar 26 2002                                              /
```

The comment lines specify the file name along with the creation date and last modification date. The creation date indicates the date when the file was created for the first time. The modification date indicates when the contents of the file were last modified.

6.8.2. Class Block

The class block consists of 6 comment lines and defines the three classes (Flight, Engine and Phase) and their instances that are used in the BADA.GPF file.

```
CC======== Class ====================================================================/
CC                                                                                   /
CC Flight = civ,mil                                                                  /
CC Engine = jet,turbo,piston                                                         /
CC Phase  = to,ic,cl,cr,des,hold,app,lnd,gnd                                         /
CC                                                                                   /
```

With:

civ	=	civil flight
mil	=	military flight
jet	=	jet engine
turbo	=	turboprop engine
piston	=	piston engine
to	=	take off
ic	=	initial climb
cl	=	climb
cr	=	cruise
des	=	descent
hold	=	holding
app	=	approach
lnd	=	landing
gnd	=	ground

6.8.3. Parameter Block

The parameter block contains the values of the global aircraft parameters. This block has 5 comment lines plus a comment line and a dataline for each parameter.

```
       CC======== Parameters List ==========================================================/
       CC                                                                                   /
       CC Name             Unit                                                             /
       CC Parameter        Flight  Engine            Phase                           Value      /
       CC                                                                                   /
       CC max. long. acc.   [fps2]                                                          /
1 ->   CD acc_long_max     civ     jet,turbo,piston to,ic,cl,cr,des,hold,app,lnd  .20000E+01 /
       CC max. norm. acc.   [fps2]                                                          /
2 ->   CD acc_norm_max     civ     jet,turbo,piston to,ic,cl,cr,des,hold,app,lnd  .50000E+01 /
       CC nom. bank angle   [deg]                                                           /
3 ->   CD ang_bank_nom     civ     jet,turbo,piston to,lnd                        .15000E+02 /
```

The parameter comment line contains the parameter name and its unit.

The parameter data line contains five fields:

(a) Parameter Field: This field identifies the parameter.

(b) Flight Field: This field identifies whether the parameter is valid for a civil flight, a military flight or both.

(c) Engine Field: This field identifies the engine type (jet, turboprop or piston) for which the parameter is valid.

(d) Phase Field: This field identifies for which flight phase the parameter is valid. 8 different flight phases are currently defined

(e) Value Field: The value field gives the value of the parameter.

The fields above are specified in the following fixed format (Fortran notation):

'CD', 1X, A15, 1X, A7, 1X, A16, 1X, A29, 1X, E10.5

The parameter list continues until 'FI' (end of file) is reached.

7. REMOTE FILE ACCESS

The files associated with BADA Revision 3.7 are accessible through the BADA Support Application (BSA). The BSA is a Web application that provides BADA users with the ability to exchange requests, as well as data files and documents, with the BADA team members. It is also used for data repository of the BADA release files and documents.

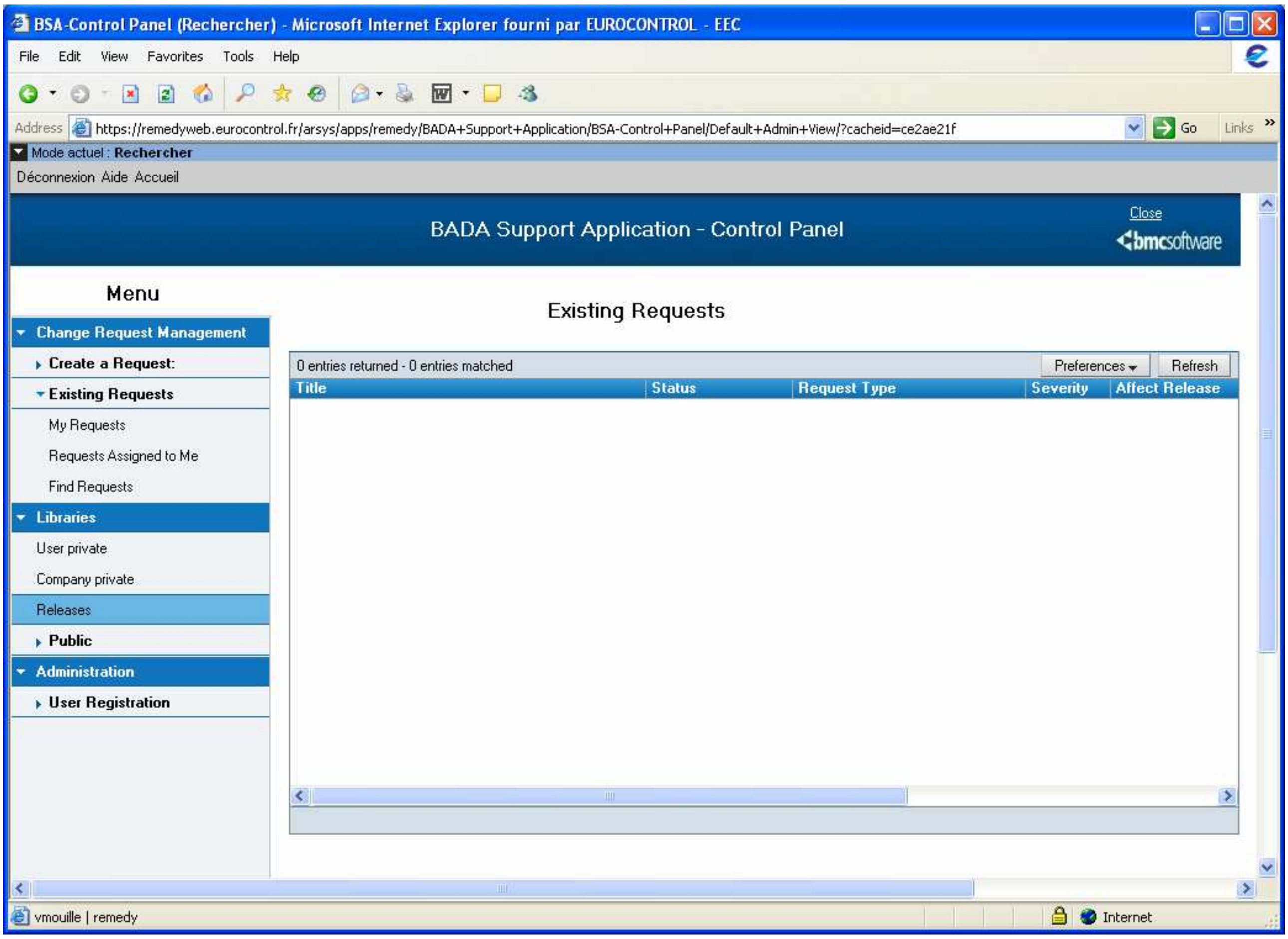
The right to use the BSA is granted to the licensed user of BADA. The application can be accessed by using a dedicated login and password as provided from the BADA team.

Once granted the access right to BSA, the user can access the application at this address:

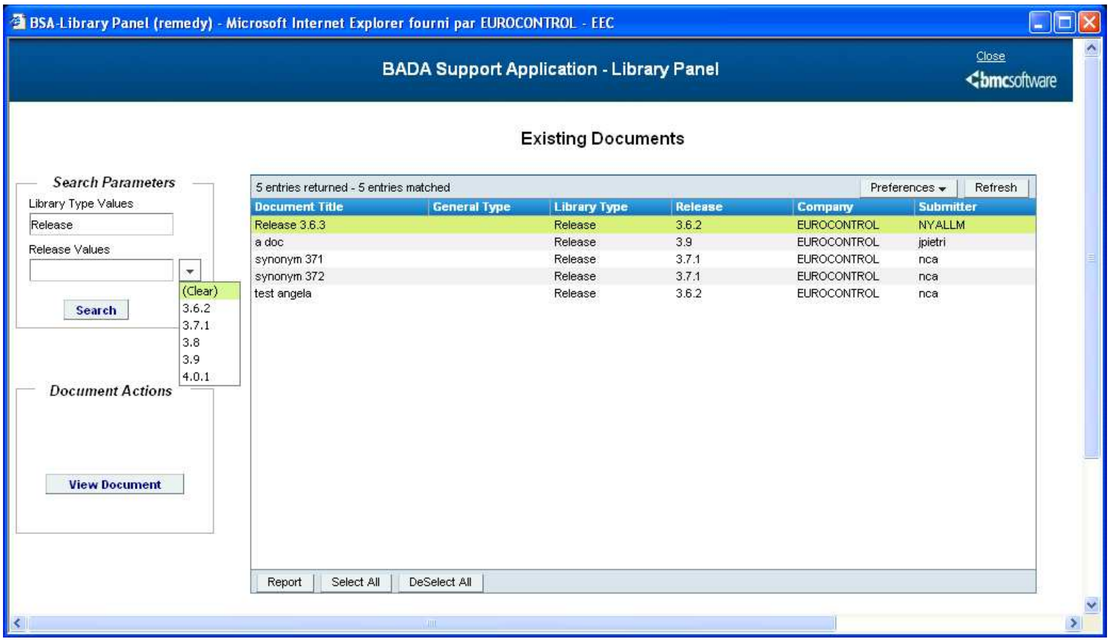
https://remedyweb.eurocontrol.fr

by using the BADA Support Application link and logging in with the provided login/password.

Once logged in, the user can access BADA releases through the Librairies→Releases item located in the main menu:



Then the release library page opens up, from where the user can download the BADA releases files:



This process, as well as the general usage of the BSA application, is described in detail in [RD11].

Note that enquiries can be addressed to the following addresses:

E-mail: eec.bada@eurocontrol.int

Fax: + 33 1 69 88 73 33

BADA web page: http://www.eurocontrol.int/eec/public/standard_page/proj_BADA.html

APPENDIX A

BADA 3.7 – LIST OF AVAILABLE AIRCRAFT MODELS

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Table 7-1: List of Aircraft Types Supported by BADA 3.7

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
A10	equiv.	FAIRCHILD	THUNDERBOLT II	FGTN	50000		M
A124	equiv.	ANTONOV	AN-124 RUSLAN	A346	41500	33613	H
A306	direct	AIRBUS	A300B4-600	A306	41000	32378	H
A30B	direct	AIRBUS	A300B4-200	A30B	39000	31967	H
A310	direct	AIRBUS	A310	A310	41000	35719	H
A318	equiv.	AIRBUS	A318	A319	39000	36365	M
A319	direct	AIRBUS	A319	A319	39000	36365	M
A320	direct	AIRBUS	A320	A320	39000	33965	M
A321	direct	AIRBUS	A321	A321	39100	35396	M
A332	direct	AIRBUS	A330-200	A332	41000	36211	H
A333	direct	AIRBUS	A330-300	A333	41000	36392	H
A342	equiv.	AIRBUS	A340-200	A343	41000	32325	H
A343	direct	AIRBUS	A340-300	A343	41000	32325	H
A345	equiv.	AIRBUS	A340-500	A346	41500	33613	H
A346	direct	AIRBUS	A340-600	A346	41000	32325	H
A388	direct	AIRBUS	A380-800	A388	43100	34330	H
A3ST	equiv.	AIRBUS	A-300ST Beluga	A321	39100	35396	M
A4	equiv.	DOUGLAS	SUPER SKYHAWK	FGTN	50000		M
A6	equiv.	GRUMMAN	INTRUDER	FGTN	50000		M
A7	equiv.	VOUGHT	CORSAIR II A7	FGTN	50000		M
A748	equiv.	AVRO	AVRO 748	ATP_	25000	21628	M
AA5	equiv.	GULFSTREAM AMERICAN	Cheetah AA-5	P28A	12000		L
AC90	equiv.	ROCKWELL	TURBO COMMANDER 690B	PAY3	33000		L
AC95	equiv.	GULFSTREAM AEROSPACE	Jetprop Commander 980	PAY3	33000		L

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
AEST	equiv.	TED SMITH	AEROSTAR	MU2_	28000		L
AJET	equiv.	DASSAULT	ALPHA JET	FGTN	50000		M
AMX	equiv.	EMBRAER	AMX	FGTN	50000		M
AN12	equiv.	ANTONOV	AN-12	C130	32000	21892	M
AN24	equiv.	ANTONOV	AN-124	F27_	25000	22778	M
AN26	equiv.	ANTONOV	AN-26	AT72	25000	20943	M
AN72	equiv.	ANTONOV	AN-72	F28_	35000		M
ASTR	equiv.	IAI	1125 Astra	FA10	45000		M
AT43	direct	ATR	ATR 42-300	AT43	25000	22700	M
AT44	equiv.	ATR	ATR 42-400	AT45	25000	23592	M
AT45	direct	ATR	ATR 42-500	AT45	25000	23592	M
AT72	direct	ATR	ATR 72	AT72	25000	20943	M
ATLA	equiv.	DASSAULT	1150 ATLANTIC	E120	32000		M
ATP	direct	BAE	ADVANCED TURBOPROP	ATP_	25000	21628	M
B1	equiv.	ROCKWELL	B1 LANCER	FGTL	41000		H
B190	equiv.	BEECH	1900	JS32	25000		L
B350	equiv.	BEECH	SUPER KING AIR 350	PAY3	33000		L
B461	equiv.	BAE	146-100/RJ	B462	31000	30350	M
B462	direct	BAE	146-200/RJ	B462	31000	30350	M
B463	equiv.	BAE	146-300/RJ	B462	31000	30350	M
B52	equiv.	BOEING	B-52 Stratofortress	FGTL	41000		H
B701	equiv.	BOEING	707-100	B752	42000	35478	M
B703	direct	BOEING	707-300	B703	42000		H
B712	direct	BOEING	717-200	B712	37000	35188	M
B720	equiv.	BOEING	B720B	B752	42000	35478	M

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
B721	equiv.	BOEING	727-100	B752	42000	35478	M
B722	direct	BOEING	727-200	B722	37000	33845	M
B731	equiv.	BOEING	737-100	T134	39000	34765	M
B732	direct	BOEING	737-200	B732	37000	34508	M
B733	direct	BOEING	737-300	B733	37000	33637	M
B734	direct	BOEING	737-400	B734	37000	33448	M
B735	direct	BOEING	737-500	B735	37000	34340	M
B736	direct	BOEING	737-600	B736	41000	39276	M
B737	direct	BOEING	737-700	B737	41000	37333	M
B738	direct	BOEING	737-800	B738	41000	34983	M
B739	equiv.	BOEING	737-900	B738	41000	34983	M
B741	equiv.	BOEING	747-100	B743	45000	30944	H
B742	direct	BOEING	747-200	B742	45000	33180	H
B743	direct	BOEING	747-300	B743	45000	30944	H
B744	direct	BOEING	747-400	B744	45000	32727	H
B74D	equiv.	BOEING	747-400 DOMESTIC	B744	45000	32727	H
B74S	equiv.	BOEING	747-SP	B742	45000	33180	H
B752	direct	BOEING	757-200	B752	42000	35478	M
B753	direct	BOEING	757-300	B753	43000	33340	M
B762	direct	BOEING	767-200	B762	43000	35861	H
B763	direct	BOEING	767-300	B763	43000	35177	H
B764	direct	BOEING	767-400	B764	45000	33210	H
B772	direct	BOEING	777-200 ER	B772	43100	34643	H
B773	direct	BOEING	777-300	B773	43100	31858	H
B77L	equiv.	BOEING	777-200 LRF, LR	B744	45000	32727	H
B77W	equiv.	BOEING	777-300 ER	B744	45000	32727	H

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
BA11	direct	BAE	111, ALL SERIES	BA11	35000		M
BDOG	equiv.	BAE	SA-3 BULLDOG	PA34	25000		L
BE10	equiv.	BEECH	KING AIR 100	D228	28000		L
BE20	direct	BEECH	SUPER KING AIR 200	BE20	32000		L
BE30	equiv.	BEECH	SUPER KING AIR 300	PAY3	33000		L
BE33	equiv.	BEECH	BONANZA 33	TRIN	20000		L
BE36	equiv.	BEECH	BONANZA 36	DA42	18000		L
BE40	equiv.	BEECH	BEECHJET 400	C560	45000	41083	M
BE55	equiv.	BEECH	BARON 55	BE58	20688		L
BE58	direct	BEECH	BARON 58	PA27	20000		L
BE60	equiv.	BEECH	DUKE 60	PA31	23000		L
BE76	equiv.	BEECH	DUCHESSE 76	DA42	18000		L
BE95	equiv.	BEECH	TRAVEL AIR 95	TRIN	20000		L
BE99	direct	BEECH	AIRLINER C99	BE99	15000		L
BE9L	direct	BEECH	KING AIR 90	BE9L	31000		L
BN2P	equiv.	BRITTEN NORMAN	BN-2A MARITIME DEFENDER	PA34	25000		L
C130	direct	LOCKHEED	HERCULES	C130	32000	21892	M
C135	equiv.	BOEING	STRATOLIFTER C-135C	B703	42000		H
C141	equiv.	LOCKHEED	STARLIFTER C-141	A310	41000	35719	H
C160	direct	TRANSALL	C160	C160	30000	25500	M
C17	equiv.	BOEING	GLOBEMASTER 3	B764	45000	33210	H
C170	equiv.	CESSNA	170	P28A	12000		L
C172	equiv.	CESSNA	SKYHAWK 172	P28A	12000		L
C177	equiv.	CESSNA	CARDINAL 177	P28A	12000		L
C182	equiv.	CESSNA	SKYLANE 182	TRIN	20000		L

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
C208	equiv.	CESSNA	CARAVAN	PA27	20000		L
C210	equiv.	CESSNA	CENTURION	TRIN	20000		L
C212	equiv.	CASA	T-12 AVIOCAR	D228	28000		L
C303	equiv.	CESSNA	CRUSADER 303	PA31	23000		L
C30J	equiv.	LOCKHEED MARTIN	C130J HERCULES	C130	32000	21892	M
C310	equiv.	CESSNA	310	PA34	25000		L
C337	equiv.	CESSNA	SUPER SKYMASTER	PA27	20000		L
C340	equiv.	CESSNA	C-340/340A	PA31	23000		L
C402	equiv.	CESSNA	402	PA34	25000		L
C414	equiv.	CESSNA	CHANCELLOR 414	PA31	23000		L
C421	direct	CESSNA	GOLDEN EAGLE 421	C421	23500		L
C425	equiv.	CESSNA	CORSAIR	PAY2	29000		L
C441	equiv.	CESSNA	Conquest	PAY3	33000		L
C5	equiv.	LOCKHEED	L-500 GALAXY	A346	41500	33613	H
C500	equiv.	CESSNA	CITATION 1	C550	43000		L
C501	equiv.	CESSNA	CITATION 1SP	C550	43000		L
C510	direct	CESSNA	CITATION MUSTANG	C510	41000		L
C525	equiv.	CESSNA	CITATION JET	C550	43000		L
C550	direct	CESSNA	CITATION II-S2	C550	43000		L
C551	equiv.	CESSNA	CITATION 2SP	C550	43000		L
C560	direct	CESSNA	CITATION V	C560	45000	41083	M
C56X	equiv.	CESSNA	CITATION Excel	C560	45000	41083	M
C650	equiv.	CESSNA	CITATION VII	H25A	40000		M
C72R	equiv.	CESSNA	CUTLASS RG	TRIN	20000		L
C750	direct	CESSNA	CITATION 10	C750	51000	45181	M
C77R	equiv.	CESSNA	CARDINAL 177RG	P28A	12000		L

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
C82R	equiv.	CESSNA	SKYLANE R182 RG	TRIN	20000		L
CL60	direct	CANADAIR	CHALLENGER 600/601	CL60	41000	39223	M
CN35	equiv.	CASA	CN-235	AT43	25000	22700	M
CRJ1	direct	CANADAIR	REGIONAL JET CRJ-100	CRJ1	41000	34334	M
CRJ2	direct	CANADAIR	REGIONAL JET CRJ-200	CRJ2	41000	36856	M
CRJ7	equiv.	CANADAIR	REGIONAL JET CRJ-700	CRJ9	41000	36458	M
CRJ9	direct	CANADAIR	REGIONAL JET CRJ-900	CRJ9	41000	36458	M
CVLT	equiv.	CANADAIR	CC-109 COSMOPOLITAN	DH8C	25000	24805	L
D228	direct	DORNIER	228	D228	28000		L
D328	direct	DORNIER	328	D328	32800	29051	M
DA42	direct	DIAMOND	TWIN STAR	DA42	18000		L
DC10	direct	MCDONNELL DOUGLAS	DC-10	DC10	39000		H
DC3	equiv.	DOUGLAS	DC-3	C421	23500		L
DC85	equiv.	MCDONNELL DOUGLAS	DC-8-50	A310	41000	35719	H
DC86	equiv.	MCDONNELL DOUGLAS	DC-8-60	DC87	42000		H
DC87	direct	MCDONNELL DOUGLAS	DC-8-70	DC87	42000		H
DC91	equiv.	MCDONNELL DOUGLAS	DC-9-10	B712	37000	35188	M
DC92	equiv.	MCDONNELL DOUGLAS	DC-9-20	DC94	35000		M
DC93	equiv.	MCDONNELL DOUGLAS	DC-9-30	DC94	35000		M
DC94	direct	MCDONNELL DOUGLAS	DC-9-40	DC94	35000		M
DC95	equiv.	MCDONNELL DOUGLAS	DC-9-50	DC94	35000		M
DH8A	direct	DE HAVILLAND	DASH 8-100	DH8A	25000	25000	M
DH8B	equiv.	DE HAVILLAND	DASH 8-200	DH8C	25000	24805	L
DH8C	direct	DE HAVILLAND	DASH 8-300	DH8C	25000	24805	L
DH8D	direct	DE HAVILLAND	DASH 8-400	DH8D	25000		M

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
E110	equiv.	EMBRAER	BANDEIRANTE	SW4_	25000	25000	L
E120	direct	EMBRAER	EMB-120 BRASILIA	E120	32000		M
E135	direct	EMBRAER	EMB-135	FA50	45000	37363	M
E145	direct	EMBRAER	EMB-145	E145	37000		M
E170	direct	EMBRAER	EMB-175	E170	41000		M
E190	direct	EMBRAER	EMB-190	E190	41000		M
E3CF	equiv.	BOEING	E-3 SENTRY	B762	43000	35861	H
E3TF	equiv.	BOEING	E-3A SENTRY	B762	43000	35861	H
EA50	direct	ECLIPSE	ECLIPSE 500	EA50	41000		L
ETAR	equiv.	DASSAULT	ETENDARD 4	FGTN	50000		M
EUFI	equiv.	EUROFIGHTER	2000	FGTN	50000		M
F1	equiv.	MITSUBISHI	F1	FGTN	50000		M
F100	direct	FOKKER	100	F100	35000	35000	M
F104	equiv.	LOCKHEED	STARFIGHTER	FGTN	50000		M
F117	equiv.	LOCKHEED	NIGHTHAWK	FGTN	50000		M
F14	equiv.	GRUMMAN	TOMCAT	FGTN	50000		M
F15	equiv.	MCDONNELL DOUGLAS	EAGLE	FGTN	50000		M
F16	equiv.	GENERAL DYNAMICS	FIGHTING FALCON	FGTN	50000		M
F18	equiv.	MCDONNELL DOUGLAS	HORNET	FGTN	50000		M
F27	direct	FOKKER	FRIENDSHIP	F27_	25000	22778	M
F28	direct	FOKKER	FOLLOWSHIP	F28_	35000		M
F2TH	equiv.	DASSAULT	FALCON 2000	F900	49000	37967	M
F4	equiv.	MCDONNELL DOUGLAS	PHANTOM	FGTN	50000		M
F5	equiv.	NORTHROP	F-5	FGTN	50000		M
F50	direct	FOKKER	50	F50_	25000	21331	M
F70	direct	FOKKER	70	F70_	37000	36565	M

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
F900	direct	DASSAULT	FALCON 900	F900	49000	37967	M
FA10	direct	DASSAULT	FALCON 10	FA10	45000		M
FA20	direct	DASSAULT	FALCON 20	FA20	42000		M
FA50	direct	DASSAULT	FALCON 50	FA50	45000	37363	M
FGTH	direct	GENERIC	MIL FIGHTER HEAVY	FGTH	50000		M
FGTL	direct	GENERIC	MIL FIGHTER LIGHT	FGTL	41000		H
FGTN	direct	GENERIC	MIL FIGHTER NORMAL	FGTN	50000		M
G222	equiv.	ALENIA	SPARTAN C-27A	ATP_	25000	21628	M
GALX	equiv.	IAI	1126 GALAXY	C750	51000	45181	M
GLAS	equiv.	STODDARD-HAMILTON	GLASAIR	BE58	20688		L
GLEX	equiv.	BOMBARDIER	BD-700 Global Express	CRJ9	41000	36458	M
GLF2	equiv.	GULFSTREAM	GULFSTREAM II	CRJ2	41000	36856	M
GLF3	equiv.	GULFSTREAM	GULFSTREAM III	CRJ2	41000	36856	M
GLF4	equiv.	GULFSTREAM	GULFSTREAM IV	CRJ9	41000	36458	M
GLF5	equiv.	GULFSTREAM	GULFSTREAM V C37	CRJ9	41000	36458	M
H25A	direct	HAWKER SIDDELEY	DOMINE HS 125	H25A	40000		M
H25B	equiv.	HAWKER SIDDELEY	HS 125-700/800	H25A	40000		M
H25C	equiv.	RAYTHEON	HAWKER 1000	FA20	42000		M
HAR	equiv.	HAWKER SIDDELEY	HARRIER	FGTN	50000		M
HAWK	equiv.	HAWKER SIDDELEY	HAWK	FGTN	50000		M
HELI	equiv.	GENERIC	HELICOPTER	P28A	12000		L
IL18	equiv.	ILYUSHIN	IL-18	C160	30000	25500	M
IL62	equiv.	ILYUSHIN	IL-62 /-62M / MK	A30B	39000	31967	H
IL76	equiv.	ILYUSHIN	IL-76	B764	45000	33210	H
IL86	equiv.	ILYUSHIN	IL-86	B763	43000	35177	H

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
IL96	equiv.	ILYUSHIN	IL-96	A343	41000	32325	H
J328	equiv.	FAIRCHILD DORNIER	328 Jet	E135	37000		M
JAGR	equiv.	SEPECAT	JAGUAR	FGTN	50000		M
JS1	equiv.	JETSTREAM	JETSTREAM 1	BE20	32000		L
JS20	equiv.	JETSTREAM	JETSTREAM 200	D228	28000		L
JS31	equiv.	BAE	JETSTREAM 31	JS32	25000		L
JS32	direct	JETSTREAM	JETSTREAM Super 31	JS32	25000		L
JS41	direct	JETSTREAM	JETSTREAM 41	JS41	26000	24685	M
K35A	equiv.	BOEING	STRATOTANKER KC-135A	B703	42000		H
K35E	equiv.	BOEING	STRATOTANKER KC-135D/E	B703	42000		H
K35R	equiv.	BOEING	STRATOTANKER K35R	B703	42000		H
L101	direct	LOCKHEED	TRISTAR L-1011	L101	42000		H
L159	equiv.	AERO (2)	L-159	FGTN	50000		M
L188	equiv.	LOCKHEED	ELECTRA L-188	C160	30000	25500	M
L29A	equiv.	LOCKHEED	JETSTART	CL60	41000	39223	M
L29B	equiv.	LOCKHEED	L1329 JETSTAR	CL60	41000	39223	M
L410	equiv.	LET	TURBOLET 410	D228	28000		L
LJ24	equiv.	LEARJET	24	C560	45000	41083	M
LJ25	equiv.	LEARJET	25	LJ45	51000	44100	M
LJ31	equiv.	LEARJET	31	LJ45	51000	44100	M
LJ35	direct	LEARJET	35	LJ35	45000	40288	M
LJ45	direct	LEARJET	45	LJ45	51000	44100	M
LJ55	equiv.	LEARJET	55	LJ45	51000	44100	M
LJ60	equiv.	LEARJET	60	LJ45	51000	44100	M
M20P	equiv.	MOONEY	MARK 201	TRIN	20000		L
M20T	equiv.	MOONEY	MARK 20T	TRIN	20000		L

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
MD11	direct	MCDONNELL DOUGLAS	MD-11	MD11	43000	31838	H
MD81	equiv.	MCDONNELL DOUGLAS	MD-81	MD82	37000	34448	M
MD82	direct	MCDONNELL DOUGLAS	MD-82	MD82	37000	34448	M
MD83	direct	MCDONNELL DOUGLAS	MD-83	MD83	37000	33513	M
MD87	equiv.	MCDONNELL DOUGLAS	MD-87	MD82	37000	34448	M
MD88	equiv.	MCDONNELL DOUGLAS	MD-88	MD82	37000	34448	M
MD90	equiv.	MCDONNELL DOUGLAS	MD-90	MD83	37000	33513	M
MG21	equiv.	MIKOYAN	MIG-21	FGTN	50000		M
MG23	equiv.	MIKOYAN	MIG-23	FGTN	50000		M
MG25	equiv.	MIKOYAN	MIG-25	FGTN	50000		M
MG29	equiv.	MIKOYAN	MIG-29	FGTN	50000		M
MIR2	equiv.	DASSAULT	MIRAGE 2000	FGTN	50000		M
MIR4	equiv.	DASSAULT	MIRAGE IV	FGTN	50000		M
MRF1	equiv.	DASSAULT	MIRAGE F1	FGTN	50000		M
MU2	direct	MITSUBISHI	MARQUISE / SOLITAIRE	MU2_	28000		L
MU30	equiv.	MITSUBISHI	MU-300	C560	45000	41083	M
N262	equiv.	NORD	262	JS41	26000	24685	M
NIM	equiv.	HAWKER SIDDELEY	NIMROD	B738	41000	34983	M
P180	equiv.	PIAGGIO	P180 AVANTI	C550	43000		L
P28A	direct	PIPER	PA-28-140 CHEROKEE	P28A	12000		L
P28B	equiv.	PIPER	PA-28-236 DAKOTA	TRIN	20000		L
P28R	equiv.	PIPER	PA-28R-201 ARROW	DA42	18000		L
P28T	equiv.	PIPER	PA-28RT TURBO ARROW 4	DA42	18000		L
P3	equiv.	LOCKHEED	ORION P-3	C130	32000	21892	M
P32R	equiv.	PIPER	PA-32R-301 SARATOGA SP	TRIN	20000		L

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
P68	equiv.	PARTENAVIA	P-68 Observer	PA27	20000		L
PA18	equiv.	PIPER	PA-18 SUPER CUB	PA34	25000		L
PA23	equiv.	PIPER	APACHE PA23-150/160	PA27	20000		L
PA27	direct	PIPER	AZTEC PA23-235/250	PA27	20000		L
PA31	direct	PIPER	CHIEFTAIN	PA31	23000		L
PA32	equiv.	PIPER	PA-32 CHEROKEE SIX	TRIN	20000		L
PA34	direct	PIPER	PA34-200T SENECA-III	PA34	25000		L
PA44	equiv.	PIPER	PA-44 SEMINOLE	TRIN	20000		L
PAY1	equiv.	PIPER	PA-A-31T1-500 CHEYENNE I	PAY2	29000		L
PAY2	direct	PIPER	PA-31T-620 CHEYENNE II	PAY2	29000		L
PAY3	direct	PIPER	PA-42-720 CHEYENNE III	PAY3	33000		L
PAY4	equiv.	PIPER	PA-42-1000 CHEYENNE 400	C510	41000		L
PC12	equiv.	PILATUS	PC-12 SPECTRE	BE9L	31000		L
RJ1H	equiv.	AI(R)	RJ-100 Avroliner	RJ85	35000	31688	M
RJ70	equiv.	AI(R)	RJ-70 Avroliner	RJ85	35000	31688	M
RJ85	direct	AI(R)	RJ-85 Avroliner	RJ85	35000	31688	M
S601	equiv.	AEROSPATIAL	SB 601 CORVETTE	C550	43000		L
SB05	equiv.	SAAB	SAAB 105	C510	41000		L
SB20	direct	SAAB	SAAB 2000	SB20	31000		M
SB32	equiv.	SAAB	LANSEN	FGTN	50000		M
SB35	equiv.	SAAB	DRAKEN	FGTN	50000		M
SB37	equiv.	SAAB	VIGGEN	FGTN	50000		M
SB39	equiv.	SAAB	GRIPEN	FGTN	50000		M
SBR1	equiv.	ROCKWELL	SABRELINER	FA10	45000		M
SF34	direct	SAAB	SF 340	SF34	25000	24369	M
SH33	equiv.	SHORTS	SH3-330	SH36	20000		M

A/C Code	Model Type	Aircraft manufacturer	Aircraft model	Synonym aircraft	h_{MO} [ft]	h_{max} [ft]	WTC
SH36	direct	SHORTS	SH3-360	SH36	20000		M
SW2	equiv.	SWEARINGEN	MERLIN II	SW4_	25000	25000	L
SW3	equiv.	SWEARINGEN	MERLIN III	PAY3	33000		L
SW4	direct	SWEARINGEN	MERLIN IV	SW4_	25000	25000	L
T134	direct	TUPOLEV	TU134A-3	T134	39000	34765	M
T154	direct	TUPOLEV	TU154M	T154	41000	37285	M
T204	equiv.	TUPOLEV	TU 204	T154	41000	37285	M
TBM7	equiv.	TBM	TBM-700	PAY3	33000		L
TOBA	equiv.	SOCATA	TOBAGO TB-10	TRIN	20000		L
TOR	equiv.	PANAVIA	TORNADO	FGTN	50000		M
TRIN	direct	SOCATA	TRINIDAD TB-20	TRIN	20000		L
VC10	equiv.	VICKERS	VC10	B762	43000	35861	H
WW24	equiv.	IAI	1124 WESTWIND	FA10	45000		M
YK40	equiv.	YAKOLEV	YAK-40	AT43	25000	22700	M
YK42	equiv.	YAKOLEV	YAK-42	DC94	35000		M

APPENDIX B

BADA 3.7 – SOLUTIONS FOR BUFFETING LIMIT ALGORITHM

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A general solution for finding the roots of a cubic expression can be found in Ref. 1. If we take expression 3.6-6, we can rewrite it to:

$$\mathrm{M}^3 - \frac{C_{Lbo(M=0)}}{k} \cdot \mathrm{M}^2 + \frac{\frac{W}{S}}{0.583 \cdot P \cdot k} = 0$$

Therefore:

$$a_1 = \frac{C_{Lbo(M=0)}}{k}$$

$$a_2 = 0 \qquad\qquad a_3 = \frac{\frac{W}{S}}{0.583 \cdot P \cdot k}$$

Now let: $$Q = \frac{\left(3 \cdot a_2 - a_1{}^2\right)}{9}$$ and $$R = \frac{\left(9 \cdot a_1 \cdot a_2 - 27 \cdot a_3 - 2 \cdot a_1{}^3\right)}{54}$$

The discriminant D is equal to: $Q^3 + R^2$. In our case D is always < 0 that means that all roots are unequal and real. A simplified computation method with the help of trigonometry is given below:

$$\mathrm{X}_1 = 2 \cdot \sqrt{-Q} \cdot \cos\left(\frac{\theta}{3}\right) - \frac{a_1}{3}$$

$$\mathrm{X}_2 = 2 \cdot \sqrt{-Q} \cdot \cos\left(\frac{\theta}{3} + 120^0\right) - \frac{a_1}{3}$$

$$\mathrm{X}_3 = 2 \cdot \sqrt{-Q} \cdot \cos\left(\frac{\theta}{3} + 240^0\right) - \frac{a_1}{3}$$

With: $$\cos\theta = \frac{R}{\sqrt{-Q^3}}$$

The solutions x1, x2 and x3 now give the possible values of M. One solution (in our case usually x1) is always negative. The others are positive with the lower one (usually x2) being the low speed buffeting limit we are looking for.

Ref. 1 Mathematical Handbook; M.R. Spiegel; 1968; McGraw-Hill book company

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